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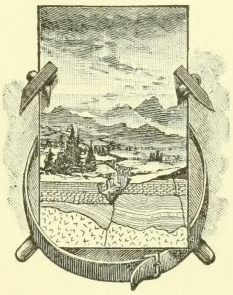

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WATER-SUPPLY PAPER 231

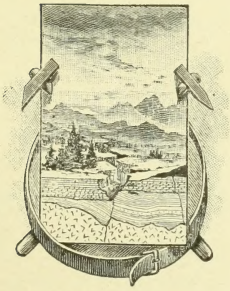
GEOLOGY AND WATER RESOURCES

OF

THE HARNEY BASIN REGION, OREGON

BY

GERALD A. WARING



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GEOLOGY AND WATER RESOURCES OF THE HARNEY BASIN REGION, OREGON.

By Gerald A. Waring.

INTRODUCTION.

CHARACTER OF RECONNAISSANCE.

Ever since white men first made their homes on the great plains of the Northwest and began to use them as ranges for cattle and horses the region about the Harney basin in Oregon has been preeminently a stock country, for the great areas of rocky plateau and of desert valley were valuable chiefly for grazing purposes. Within the last few years, however, many settlers have immigrated to this northwestern region, mainly perhaps because of the growing scarcity elsewhere of Government land worth homesteading. This recent influx has brought the region into notice and has given rise to a demand for reliable information concerning it, to supply which the writer was detailed to make a reconnaissance of Harney Valley and adjacent territory. Seven weeks during the summer of 1907 were spent in this work, which is an eastward continuation of a similar study that was carried out in Lake County in the fall of 1906. The areas covered during each of these seasons is shown on the index map (Pl. I). Special attention was paid to the water supply, both from streams and from underground sources, and to the structural geology of the region in its relation to artesian conditions.

With the exception of those compiled from the Land Office plats no maps of this area have been published. Since a topographic base is essential to a careful study of underground water conditions as affected by drainage basins and rock structures, the accompanying map (Pl. II, in pocket) has been prepared from all available data, and from field observations made during the course of the examination. This work was secondary to the main purpose of the investigation, and it is realized that there are many inaccuracies in it, but for the purpose of showing the main elements of the relief and drainage and their relations, and as a basis for a study of ground-water conditions, the map is considered to be sufficiently trustworthy.

ACKNOWLEDGMENTS.

Occasion is here taken to thank the several ranchers and settlers who aided the writer in many ways during the field work. Especially is appreciation expressed to Dr. W. L. Marsden, of Burns, for much information, and to Mr. J. W. Hanley for the hospitality extended at the ranches that he superintends.

PREVIOUS STUDY.

In 1882 I. C. Russell made a very general examination of this region in connection with his study of Quaternary lakes.[a] At this time he visited Alvord Valley, traveling through it from Alvord Lake to its northern end; thence he crossed the divide into Harney Valley, followed along its eastern and northern borders, and passed westward into Lake County. In his paper he describes the general features of this region, especially its geologic structure, in which faulting is the predominant factor, and speaks of the great lakes that existed in its valleys during Quaternary times. In the summer of 1902 he made a second trip through southeastern Oregon, this time more especially to examine its geology and to note its water supply. The results of this study appeared in two publications of the Survey—a water-supply paper (No. 78)[b] and a bulletin (No. 217).[c] In his water-supply paper he describes the kinds of rocks and their geologic structure, speaks in greater detail of the valleys and their water supply, and gives evidence which he regards as indicating the existence of water under artesian pressure in the rocks underlying Harney and Whitehorse valleys. In his bulletin of the same year he treats more fully of the structure and the classes of rocks, especially of the recent volcanic materials, and also describes the character of the several lakes. In 1903 he made a third journey through this part of the Northwest and gathered additional information concerning northern Harney County, which is published in another bulletin of the Survey.[d] In this report he describes the rocks and rock structures along the route traversed, and also mentions the prominent mountains and their characters. In speaking of the water supply he names the several major streams, and considers the possibilities of water storage on them for irrigation in the valley lands. In his discussion of underground water he calls attention to the shallowness of the ground-water level throughout the valleys and the plentiful supply of such water, and advocates the drilling of deep wells for artesian flows.

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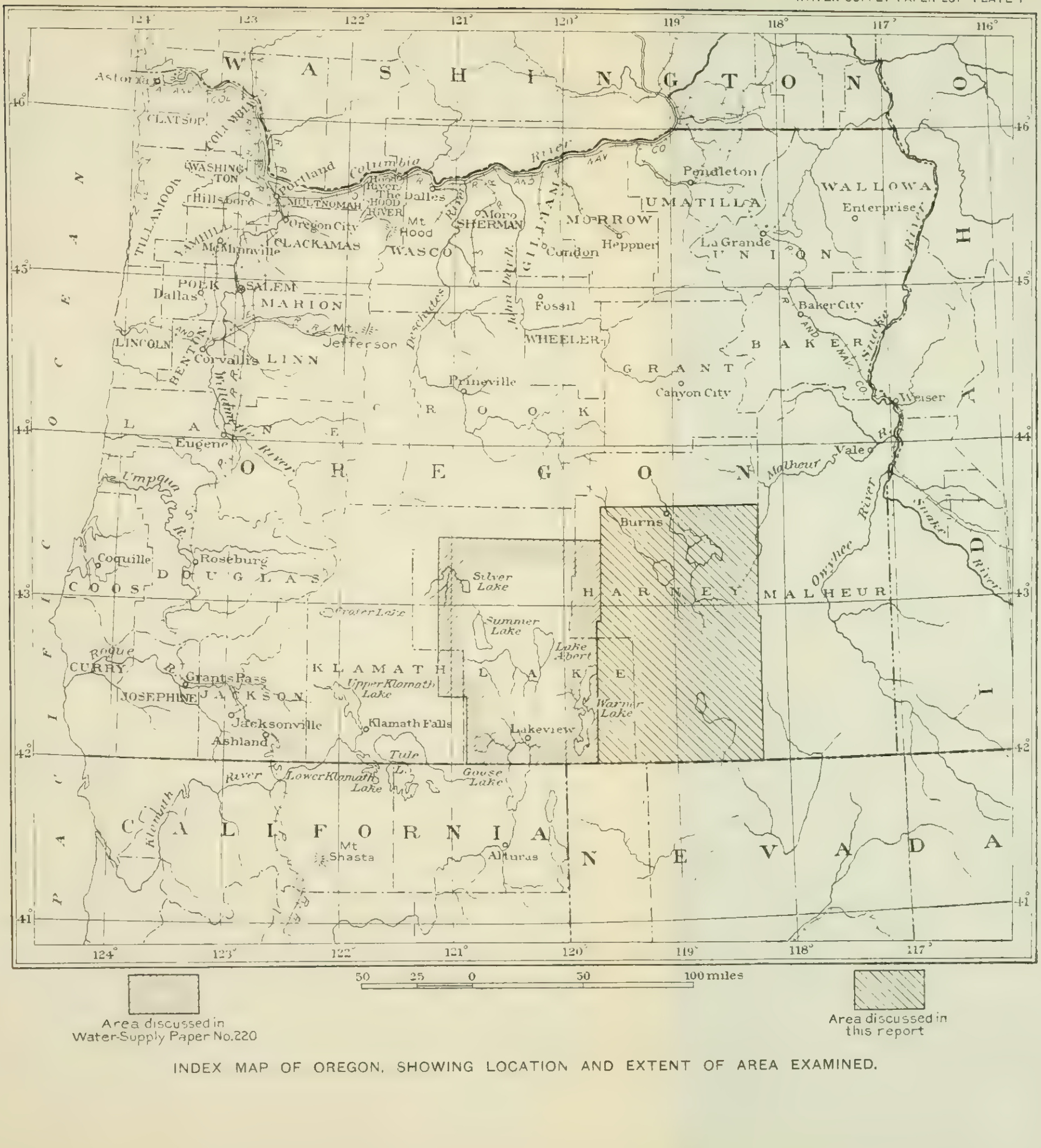
[a] Russell, I. C., A geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey; 1884, pp. 431–464.

[b] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Supply Paper U. S. Geol. Survey No. 78, 1903.

[c] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903.

[d] Russell, I. C., Preliminary report on the geology and water resources of central Oregon: Bull. U. S. Geol. Survey No. 252, 1905.



INDEX MAP OF OREGON, SHOWING LOCATION AND EXTENT OF AREA EXAMINED.

As their titles indicate, these papers also treat of the country to the east and to the west of Harney County. Concerning the country immediately north of it there appears to be no literature; while for that on the south an article by James Blake[a] on the Puebla (Pueblo) Range of mountains, in Nevada, is the principal publication. This paper treats mainly of the structure of the mountains and the kinds of rocks that were noted in them.

GEOGRAPHY.

TOPOGRAPHY.

GENERAL CHARACTER.

As a whole southeastern Oregon forms a great uneven plateau region with an average elevation of between 4,000 and 5,000 feet. Large areas of it are nearly level or only gently undulating, but the stretches of table-land are broken in a few places by extensive escarpments, which trend in general from north to south. The escarpments border flat valleys, which also occupy a great part of this region, usually lying but a few hundred feet lower than the plateaus. These valleys contain shallow lakes, or at least playas or wet-weather lakes, but for the most part their surfaces form wide level expanses of alluvial sagebrush-covered plain.

The largest of these is Harney Valley, which comprises roughly 700 square miles of plain, marsh, and lake surface, in the central part of Harney County. In the southeast lies Alvord Valley, a long, narrow basin limited by escarpments and rugged hills, while in the southwest the Warner Lakes lie in a similar basin, bordered by great cliffs. Catlow Valley, in the south-central part of the area studied, is a fourth area of level plain, which lies several hundred feet higher than the other valley lands. On the east its edge is marked by bold escarpments, but westward its surface rises gradually to the higher plateau.

These valleys are not without breaks in their monotonous levels, for half-buried buttes rise here and there. Many small sand dunes and hillocks also dot their floors, and in some places flood water has cut minor channels in the loose alluvial material of their surfaces.

The plateau character is best developed in the west-central part of the area examined and extends westward across Lake County, but it is broken by escarpments that border the lake basins existing there. Eastward the same topography persists, but it is deeply notched by Owyhee River and its tributaries. Northward the surface rises in more mountainous slopes to the Strawberry Mountains, and the plateau-like character is not so well developed. In the southeast, also, a long gentle upward slope culminates in the crest of Steens Moun-

[a] Blake, James; On the Puebla Range of mountains: Proc. California Acad. Sci., vol. 5, 1875, pp. 210–214.

tain, and, together with the southward extension of this higher mass in the Pueblo Mountains, forms a different type of relief from that of the remarkably uniform plateau country.

The great mass of Steens Mountain[a] is the dominant topographic feature in southeastern Oregon, rising as it does to an elevation well above 9,000 feet. Along the western border of Alvord Valley it extends, trending east of north, from opposite Alvord Lake for a distance of 40 miles or more. Its eastern face is a precipitous escarpment, which in its central, higher portion rises over 5,000 feet above the valley at its base and is deeply scored by ravines and canyons. From its crest the surface slopes uniformly northwestward, for a distance of 15 or 20 miles, to the lowlands of the Harney basin and the western plateau country. The northern end of the mountain merges with lower though rugged slopes and buttes, while southward its limit is marked by an escarpment that swings northwestward along the border of the Catlow basin. Southward the mountainous character persists in the Pueblo Range, but these mountains do not have the remarkable features of an eastward-facing scarp and long gentle westward slope, which are so pronounced in Steens Mountain.

STREAMS.

Within the western United States there is a great area from which no streams flow to the ocean, hence it is known as the Great Basin area of interior drainage. The Harney drainage basin occupies the northern end of this area. North of it are the tributaries of John Day River, and on the east the streams join Malheur River and thence unite with Snake River, but to the south and west the streams are small and have no outlet to the ocean.

Within the Harney basin Silvies River from the north and Donner und Blitzen River and its tributaries from the south flow into Malheur Lake and carry the larger part of the run-off. In the other basins smaller streams flow from the surrounding slopes to the valley lands. Those that rise in Steens Mountain are perennial, but those having their sources in the western part of the county are dry during the greater part of the year.

LAKES.

The run-off of the nortneastern part of the area studied ultimately reaches the ocean through Malheur River, the Snake, and the Columbia; that of the rest of the region collects in the numerous depressions of the great plateau, and where it is sufficient in quantity perennial lakes are formed.

[a] On some maps this name appears as Stein or Steins Mountain, but as it was named for Col. Enoch Steen it seems proper to adopt the spelling here used.

Of such water bodies in the Harney basin region, Malheur Lake has the largest area, but it is very shallow, probably not over 10 feet at the deepest; and for some distance out from its margin the water is only a few inches deep. As its basin slopes so very gently, the lake varies much in extent, being usually greatest in May and June and least in January and February, when wide areas of tule land and mud flat are left around its borders. During high water it extends 16 or 18 miles eastward from Narrows and has a maximum width of about 8 miles, while at its lowest stage it shrinks to perhaps two-thirds that size.

Harney Lake, 7 or 8 miles across, is more definitely limited, for although its surface also fluctuates several feet during the year it lies in a deeper basin, with steeper shores, so that its extent is little affected by the change in depth. During the greater part of the year a shallow strait unites Harney and Malheur lakes, making them parts of one continuous water body.

Silver Lake, on the western border of the Harney basin, is supplied mainly by the overflow from Silver Creek during the spring season. Like the other lakes it is shallow, and all of its bed, which is 3 or 4 miles across, is not covered by water in the fall.

Warner Lake, to the southwest, lies in a long narrow valley which in its southern portion is bordered on each side by great cliffs. The supply to the lake is meagre, from only a few small streams and the rain and snow that fall in the lowland itself, so that during the autumn the lake shrinks to a number of detached water bodies or a chain of lakes.

In Alvord Valley, on the eastern side of Steens Mountain, Alvord Lake in wet winters extends northward and covers the desert of the same name to a depth of a few inches. During the summer months the desert is a barren mud plain, while the lake itself shrinks to a small area bordered by an alkali-incrusted flat. Juniper and Mann lakes are smaller fresh-water lakes in separate depressions in the northern end of Alvord Valley. They are supplied mainly by creeks rising in the slopes of Steens Mountain, upon whose cliffs lingering patches of snow furnish water to the streams throughout the year.

CLIMATE.

CONTROLLING CONDITIONS.

The elevation of most of the valleys of Harney County is about 4,100 feet, while that of the plateaus is from 4,500 to 5,500 feet. This rather high elevation renders the climate colder than it would be in this part of the Northwest were the country lower.

The Cascade Range, which trends from north to south through the State, from 125 to 200 miles west of the area under discussion. acts

as a great wall separating the abundantly watered coastal side from the eastern portion, where the precipitation is slight. This lack of moisture, combined with the low mean temperature due to elevation, gives the region an arid and a rather severe climate.

RECORDS.

In Harney County and adjacent territory weather observations have been made at four volunteer stations, and partial records extending over several years have been kept. The following summaries of precipitation and temperatures at these stations are from records furnished by Edward A. Beals, district forecaster of the U. S. Weather Bureau, at Portland, Oreg.

Records of precipitation at Burns, Oreg.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1890	.....	.....	0.15	0.00	0.40	0.00	.....	.....	.....	.....	.....	0.03	.....
1891	0.16	.....	.....	.....	.....	.....	.....	.....	0.10	0.00	3.77	1.69	.....
1892	1.05	0.00	.25	.25	1.65	.00	0.01	Tr.	.75	.....	Tr.	.16	4.12+
1893	1.35	.50	.60	.10	Tr.	Tr.	Tr.	0.00	1.25	1.04	.....	.80	5.64+
1894	1.90	1.70	.70	.70	1.80	1.30	.15	.00	.00	1.85	.00	.....	10.10+
1895	1.20	.00	.00	.00	.00	.....	.00	.00	.....	.00	.....	.....	.....
1896	1.50	.....	2.10	1.30	.....	.....	.60	.....	.70	.00	1.00	.60	.....
1897	1.10	1.10	.60	1.10	Tr.	.....	.75	.25	2.50	.25	1.35	.95	9.95+
1898	1.45	.....	Tr.	Tr.	1.52	.32	.00	Tr.	Tr.	Tr.	1.40	.20	4.89+
1899	1.90	.00	.61	.57	.16	.....	.....	.....	.....	1.32	4.55	1.80	.....
1900	Tr.	1.80	.54	1.15	.34	.34	.00	.17	.24	.62	.47	.90	6.57
1901	1.20	1.67	.30	.34	.12	.15	.00	.22	.07	.07	.....	.....	.....
1902	.72	3.31	.90	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1903	.....	.....	.....	.....	.....	.....	.....	.....	.....	.34	3.53	.74	.....
1904	.77	2.52	2.88	1.50	.....	.71	.58	.15	1.67	.86	.37	2.84	14.85+
1905	1.93	.28	1.89	.65	.53	2.45	.01	.15	.62	.55	.81	.57	10.44
1906	4.24	1.38	3.94	.27	2.43	1.41	.36	.43	.59	.23	.96	1.88	18.12
1907	2.08	2.36	2.33	1.06	.51	1.59	.26	.10	1.01	.27	.51	3.49	15.57

Records of precipitation in Happy Valley, Oregon.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1890	.....	.....	.....	1.38	0.50	1.75	0.00	0.26	0.54	0.09	.....	.....	.....
1891	0.65	2.70	2.35	1.57	3.14	2.55	2.12	.24	.74	.32	0.99	1.94	19.31
1892	.57	.57	1.62	2.12	1.76	.83	.39	.00	.77	.36	1.06	1.05	11.10
1893	1.09	1.11	1.33	2.16	1.39	.00	.32	.00	1.63	1.15	2.24	.65	13.07
1894	1.72	1.78	1.48	1.25	3.25	2.76	.53	.27	.77	1.74	.24	.87	16.66
1895	.66	.48	.33	1.41	1.87	.01	.20	.12	2.29	.00	.30	2.08	9.75
1896	1.76	.55	.....	2.02	2.02	.34	.20	1.51	.71	.89	2.08	.74	12.83+
1897	1.32	2.53	1.54	2.33	1.39	1.61	.33	.09	.36	.39	1.78	1.74	15.41
1898	1.17	.62	.35	.48	2.45	.76	.04	.46	.50	.88	1.89	.59	10.19
1899	1.39	1.57	2.79	1.62	2.15	.42	.04	1.05	.05	1.74	2.08	1.72	16.62
1900	1.67	1.56	.54	1.44	2.06	1.13	.06	.73	1.78	.....	.....	.....	.....

Records of precipitation at Riverside, Oreg.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	.....	.....	.....	.....	.....	.....	0.35	0.10	0.14	0.15	1.86	1.61	.....
1898	0.66	0.25	Tr.	0.14	1.17	0.31	.11	.06	.21	.29	.....	.28	3.48+
1899	1.68	1.25	1.95	.82	1.38	.....	.15	Tr.	Tr.	1.67	1.21	2.06	12.17+
1900	.87	.59	.50	1.23	.81	.95	.00	.50	.61	1.05	.....	.....	.....
1901	.40	2.12	.14	1.02	.50	.35	Tr.	.34	.38	.42	.44	1.24	7.35
1902	.65	2.43	.....	.93	.....	.....	.15	.17	.31	.21	1.01	.....	.....
1903	2.44	.50	1.02	Tr.	.40	.....	.....	.52	.....	.10	.....	.15	.....
1904	.16	1.05	.60	1.60	.45	.....	.50	.70	.65	.98	.25	1.15	8.09+
1905	2.10	.55	.60	.42	2.16	1.47	.27	Tr.	.05	.....	.45	.....	.....
1906	2.15	1.70	3.93	.50	2.82	1.07	.....	Tr.	.29	.15	.35	2.20	15.16+
1907	.60	2.39	1.39	.69	1.15	1.19	1.31	.....	.55	.74	.10	2.70	12.63+

Records of precipitation at the P ranch, Oregon.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	.....	.....	0.30	0.15	.....	.....	0.00	0.16	1.14	0.10	1.42	1.72	.....
1898	0.79	0.11	.21	.10	2.37	0.33	.00	Tr.	Tr.	.00	2.00	.00	5.91
1899	.00	.01	1.34	.02	1.17	.00	Tr.	.87	.00	.....	.....	2.61	.....
1900	1.27	.28	.24	1.11	1.08	.00	.00	.....	.....	.....	.....	.....	.....

Monthly, seasonal, and annual means of temperature and precipitation at stations in southeastern Oregon.

Month.	Burns.[a]				Happy Valley.[b]				Riverside.[a]			
	Mean temperature.	Mean maximum temperature.	Mean minimum temperature.	Mean precipitation.	Mean temperature.	Mean maximum temperature.	Mean minimum temperature.	Mean precipitation.	Mean temperature.	Mean maximum temperature.	Mean minimum temperature.	Mean precipitation.
	°F.	°F.	°F.	*In.*	°F.	°F.	°F.	*In.*	°F.	°F.	°F.	*In.*
December	26	49	−1	1.2	30	56	0	1.3	28	54	0	1.4
January	23	48	−8	1.4	29	54	−1	1.2	28	52	−6	1.1
February	27	51	−5	1.3	31	56	−1	1.4	33	59	−1	1.3
Winter	25	49	−5	3.9	30	55	−1	3.9	30	55	−2	3.8
March	33	62	3	1.1	36	67	10	1.4	40	66	9	1.1
April	43	73	18	.6	44	76	18	1.6	48	81	18	.7
May	49	82	22	.7	50	83	22	2.0	54	91	22	1.2
Spring	42	72	14	2.4	43	75	17	5.0	47	79	16	3.0
June	57	89	27	.7	57	89	26	1.1	63	97	28	.9
July	66	97	33	.2	64	96	30	.4	70	105	33	.3
August	65	96	31	.1	63	94	32	.4	70	103	33	.2
Summer	62	94	30	[c]1.0	61	93	29	1.9	67	102	31	1.4
September	53	88	22	.7	54	88	23	.9	58	94	24	.3
October	46	79	16	.5	45	78	14	.8	47	81	15	.6
November	34	65	4	1.4	37	67	4	1.4	36	69	6	.7
Fall	43	77	14	2.6	45	78	14	3.1	47	81	15	1.6
Annual	43	73	13	[d]9.9	45	75	15	13.9	48	79	15	9.8

[a] Computed from records of monthly mean, maximum, and minimum temperatures, and monthly precipitation, furnished by Edward A. Beals, district forecaster, U. S. Weather Bureau, Portland, Oreg.

[b] From Bulletin Q of the U. S. Department of Agriculture: Climatology of the United States, by Alfred Judson Henry. Chapter on Oregon by Edward A. Beals, p. 967. (Mean precipitation for June corrected from original records.)

[c] Given as 0.66 on Pl. I of First Biennial Report of the Oregon State Engineer, 1906.

[d] Given as 9.33 on Pl. I of First Biennial Report of the Oregon State Engineer, 1906.

A study of the precipitation records shows that, as in other arid regions, the rainfall varies greatly from year to year, a fact that in regions of slight rainfall has a vital bearing on the possibilities of dry farming. During the years 1904–7 the rainfall at Burns was above the average, in two of them being over 50 per cent above the normal, and in 1906 nearly twice the average amount. But the incomplete records of earlier years indicate that in some of them the rainfall was only about half the mean for the last seventeen years. In the last table, from the means of precipitation prepared from the figures of the preceding tables, it is seen that the moisture is fairly well distributed through the winter and spring months. As is to be

expected, the rain and snow fall is greater in Happy Valley, near the mountains, than it is over the more open country near Burns, owing mainly to a greater spring rainfall. Near the protecting mountains the mean annual temperature is somewhat higher than in the open valley land, perhaps because the portions near the mountains are sheltered from the desert winds; and for similar reasons the extremes of temperature are not so great in those sections. But the temperature has a considerable range, often going below zero in winter, and occasionally reaching 100° in summer. Sudden or extreme changes are unusal, however, and though the nights of summer are cool there is a considerable period in which there is little danger of frost. Of the Harney basin region as a whole it may be said that the average rainfall is between 10 and 15 inches, and the mean annual temperature between 45° and 50°.

VEGETATION.

Only along the northern border of the area mapped on Plate II are the slopes timbered, hence it is from this portion that lumber for the country to the south is obtained. The growth consists almost wholly of open forests of yellow pine. The dense growth of young trees in portions of these open forests is gratifying, both as a source of future lumber supply and as an aid to the lengthening of the summer flow of the streams. Junipers are scattered over parts of the plateau lands, and furnish good fence-post material, which is used extensively in inclosing fields and homesteads, while cottonwoods grow along the upper courses of the mountain streams. But the gray sagebrush, which is so characteristic of the Northwest, is the chief growth over the plateaus and mountain slopes as well as the valley lands. This brush extends even to the crest of Steens Mountain, over 9,000 feet above sea level, though at this elevation it is dwarfed to a few inches in height, and its stalks are reduced to tough twigs that carry only a few leaves.

The remarkable absence of timber on Steens Mountain has been discussed by Russell,[a] who attributed it to the overlapping of the lower border of the cold timber belt and the upper border of the dry timber belt. The former extends down the mountain slopes from the summit and prevents timber growth in the higher elevations, while the deficiency of moisture on the lower slopes prevents the growth of pines there. The main exceptions to the scanty covering of vegetation on this mountain are the cottonwoods along the streams, a small group of firs in one canyon, and occasional patches of mountain mahogany on the upper slopes.

It is from the timbered slopes in the northern part of the county that fuel for the greater part of the population at Burns and at

[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903, p. 11.

Harney is obtained. When snow is on the ground, logs are easily skidded down from the mountains and can then be cut up into stove wood at leisure. In the southern part of the county dependence is placed mainly on the scattering junipers, which have already been largely cut for this purpose and for fence posts. In many parts the sagebrush is the most accessible fuel, though it is a disagreeable one to handle and burns out quickly.

GAME.

A few mountain sheep are said still to inhabit the more inaccessible parts of Steens Mountain, while deer and antelope are rather numerous, and in winter come down into the valleys to feed. It is affirmed by residents that during severe weather a few elk still come down from the mountain and mingle with the cattle on the Alvord ranch. Good trout fishing may be had in the larger mountain streams during the summer. Of feathered game, an occasional flock of sage hens may be seen on the dry plateaus or in the valleys, while thousands of waterfowl frequent Malheur and Harney lakes and the tributary marsh lands. The wagon bridge at Narrows is locally famous as a stand for sportsmen, who take advantage of the flight of ducks and geese over the narrow strip of water connecting the two lakes.

SETTLEMENTS.

Within the area studied there were fourteen post-offices in the spring of 1909. Burns, the county seat of Harney County, is a town of 800 or 1,000 inhabitants. It is the initial or terminal point of four stage lines that connect with railroads at Shaniko and Austin on the north, Vale on the east, and Winnemucca, Nev., on the south. These places are respectively about 213, 102, 131, and 284 miles distant from Burns, according to the post-route map. Harney, the second town in size, has perhaps 100 inhabitants. Lawen and Narrows, near Malheur Lake, and Denio, near the Nevada line, each consists of a small group of houses, with a general store and accommodations for travelers. At Riley, Diamond, and Andrews one can also obtain a few supplies and accommodations for the night. Smith and Venator post-offices are at ranch houses, while Harriman, Alberson, Waverly, and Voltage post-offices were recently established at new homesteads, the former being located near the line of a preliminary railroad survey of the Northern Pacific system.

For the southwestern part of the area under discussion the nearest store and post-office is at Plush, in Warner Valley. Two slightly traveled roads cross the plateau between it and Harney Valley. The most direct road runs west of south from the Double O ranch, near Harney Lake, to Warner Valley, and along its western side to Plush. From the P ranch, at the head of the marsh of Donner und Blitzen

River, another road leads southwest across the Catlow basin and follows the general trend of Rock Creek to its upper course, then turns west and descends the escarpment into Warner Valley. On this road there are two ranches on upper Rock Creek, those of Messrs. E. T. Flook and Steve Young, which are used as stopping places by travelers. On the other road there is no habitation between the Double O ranch and the Bluejoint ranch, a distance of 65 or 70 miles. In summer the only two watering places on this road are those at Buzzard Spring and Mule Spring.

INDUSTRIES.

GRAZING.

As stated in the introduction, grazing is the most important industry in this region. The plateaus and valleys furnish a cattle range that formerly was restricted only by the location of watering places; and the bunch grass has in the past been plentiful enough to supply feed to thousands of head of stock. In the early fall the herds are rounded up, the several brands are separated by their owners, and the animals intended for market are driven to the railroad. The others are pastured for the winter on the marsh lands, practically all of which are controlled by the larger stock owners. During the summer these marshes are mowed and the wild hay is stacked for winter feeding.

Within the last few years the high price of sheep and the low price of cattle have led to the introduction of rapidly increasing numbers of sheep. As in every other grazing region that they have entered, sheep are rendering the none too abundant range unfit for cattle and horses, except in those portions of the high desert from which the scarcity of water excludes them; and already in the mountain regions the results of overgrazing are very apparent. The influx of settlers and the fencing of valley land has also restricted the cattle range. Of late years these three factors—low prices, the introduction of sheep in large numbers, and the settlement of the valley land—have caused a very noticeable retrenchment in the cattle business. But it seems that this will always be mainly a stock-raising country, because of the great areas of plateau that are fit for little except grazing; and it may be that, as has been found true in the Middle West, when the limited areas of arable land have been brought under cultivation and are producing crops of alfalfa, grain, and other feed, many more head of stock will be marketed than when the entire region was unrestricted range.

AGRICULTURE.

Comparatively little farming has yet been done within this region, though most of the common fruits and vegetables are grown for home use. Increasing acreages of barley, wheat, and oats are also being

raised each year, to supply the increasing demand for grain and hay, while rye is a common first-year crop on new land. In a few places, where water is available for irrigation, there are small fields of alfalfa, but much lowland on which this forage crop might be more profitably raised is still given over to the natural grasses, which in the spring are irrigated by overflow water from the larger streams.

The rapid influx of settlers during the last two or three years promises to make farming a much more important means of livelihood than it is at present. While it may be found easy to raise such grains, fruits, and vegetables as are required at home for the table and for stock feed, the remoteness of the region from railroads limits the market for farm produce to the amount required for local consumption; and until a ready outlet to wider markets is obtained, the development of the country can not be expected to proceed very rapidly.

LUMBERING.

A sawmill in the mountains north of Burns and one in the timber a few miles north of Harney supply lumber for the county. Yellow pine is almost the only kind of timber available, the rough material being sold at from $12 to $14 a thousand board feet at the mill.

MINERALS AND BUILDING STONE.

During the last few years renewed interest has been aroused in indications of copper in the mountains west of Denio. Some prospecting has been done and a few good specimens of carbonate ore and the native metal have been found, but no body of ore has been uncovered, nor has development work been undertaken to any extent.

Deposits of volcanic ash and coarser fragmental material form beds of tuff that in a number of places have been quarried to some extent to obtain building stone. At Burns squared blocks of rhyolitic tuff from the neighboring slopes have been employed in the construction of a church and a bank building; and rougher blocks of the same material have been used in several other buildings, as well as in foundations and retaining walls. But the irregular mottling of this dark-brown stone, which contains fragments of lighter-colored material, is not very pleasing when put to this use. At Narrows a light-buff tuffaceous sandstone has been used in the construction of one or two buildings, and for chimneys, foundations, and similar purposes. In other parts of the county similar material is also quarried for such uses.

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GEOLOGY.

THE ROCKS AND THEIR SUCCESSION.

AGE OF THE ROCKS.

The rocks of the Harney basin region consist almost wholly of effusives and varieties derived from them. The greater part of these seem unquestionably to belong to the same period of outpouring as those that cover northern Oregon and southern Washington, which are known as the Columbia River basalt. These latter have been determined to be of Miocene age by fossils found along Columbia and Yakima rivers and in the basin of John Day River, in sediments that are interbedded with the lavas. But in at least one portion of the area covered by this report there are rocks of an older series than that of the effusives, and successive flows of these effusives also bear such relation to each other as to warrant the recognition of the following classes of material in addition to the main Miocene lava flows: Plutonic and metamorphic rocks, earlier effusives, tuffaceous sediments, later eruptive lava, and the unconsolidated sediments filling the valleys. The approximate extent of these several classes of material is shown on the geologic map (Pl. III, in pocket), but their boundaries as there shown must be understood to be indicated only in a very general way; for the main purpose of the examination did not permit their detailed mapping.

PLUTONIC AND METAMORPHIC ROCKS.

Pueblo Mountain and the range south of it are composed of rocks that belong to an older series than do the lavas to the north. These mountains were only cursorily examined, but from float specimens that were collected along the eastern base of the range they appear to be made up of andesitic porphyries, micaceous schists, and granitic rocks, which have been more or less extensively affected by mineralizing agents.

In a paper published in 1875 Dr. James Blake[a] describes the southern extension of these mountains in Nevada. There he found micaceous and talcose schists and metamorphic limestones, which dip away from the mass of porphyry that forms the crest of the eastern ridge of the range.

The rocks of this range are the oldest that were noted, but to what earlier period than the lavas they belong there are no facts at hand to suggest.

EARLIER EFFUSIVES.

In a few places masses of lava were noticed that from their structure and positions seem to be older than those associated with the main flows, for they show little bedding structure and rise high

[a] Blake, James, The Puebla Range of mountains: Proc. California Acad. Sci., vol. 5, 1875, pp. 210–214.

above the surrounding lavas, which extend only part way up on their bases and apparently never completely covered them. Of these masses, Iron Mountain and Flagstaff Butte are the most prominent. The slopes of the former are composed largely of rock that has been identified by E. S. Larsen, jr., as hornblende basalt. From its shape and the relation of its material to the surrounding olivine basalt the mountain is considered to be an early volcanic cone.[a] Flagstaff Butte is composed of rhyolitic rocks, and has the characteristics of an old volcanic neck, or plug. It is possibly the source from which issued the sheets of greenish rhyolite that is the surface rock west of it.

On the western side of Alvord Valley, opposite the middle portion of Alvord Desert, and also 4 or 5 miles south of Andrews, there are hills of light-colored rhyolite. This rock apparently underlies the great series of basaltic flows that forms the mass of Steens Mountain, and it is thought to belong to an older period of effusion than the basalt.

TUFFACEOUS SEDIMENTS.

In five localities sedimentary beds of fine-grained volcanic tuff and ash were noted. In Alvord Valley, west of the Alvord ranch, beds of siliceous tuffs are exposed at the base of Steens Mountain. The thickness of these beds is given by Russell[b] as over 1,000 feet. There is a prominent outcrop of the material between the elevations of about 5,300 and 5,200 feet, but the lower portion of the deposit is obscured by talus and stream wash.

Northwest of Tumtum Lake, light-colored tuffaceous rocks form hills on the western side of Alvord Valley. These beds form a lower topographic belt, distinct from that of the basaltic escarpment farther west. The tuffs are less siliceous than those farther north, and in them the bedding is better developed. A ripple-marked surface is usually presented along parting planes. These tuffs, like those west of the Alvord ranch, underlie the main basaltic flows, or at least are near the base of this series.

East and northeast of Flagstaff Butte, in the flat valley of Willow Creek, there are nearly horizontal beds of fine white volcanic ash, which are interspersed every few inches with more sandy layers, and are overlain by coarse fragmental tuff. Mr. J. C. Beatty has opened a quarry in the fine-grained beds about 2½ miles east of Flagstaff Butte, in which a very good section of the material is exposed. From the white layers of volcanic ash beautifully preserved plant

[a] See Russell, I. C., Preliminary report on the geology and water resources of central Oregon: Bull. U. S. Geol. Survey No. 252, 1905, p. 47.

[b] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903, p. 16.

remains were collected, which have been identified by F. H. Knowlton, paleobotanist of the U. S. Geological Survey, as of Upper Eocene age. The specimens examined contained leaves of the fossil oak, alder, birch, willow, and maple. Of these trees the following species were recognized:

Quercus consimilis Newberry.
Quercus simplex Newberry.
Alnus serrulata fossilis Newberry.
Betula heterodonta Newberry.
Salix perplexa? Knowlton.
Acer osmonti Knowlton.

Near the southern base of Flagstaff Butte, at the eastern end of the small valley along Trout Creek, similar tuffaceous sediments are exposed that dip gently eastward beneath the basalts.

The siliceous sediments noted at the two localities in Alvord Valley possibly are also of the same series as those near Trout and Willow creeks, but the evidence that was obtained is not sufficient to warrant correlating them definitely with these Eocene deposits.

The fifth locality where sedimentary beds were noticed is south of Narrows, where an area of a number of square miles is covered by a light-colored felsitic tuff or sandstone. Near the southeast border of Harney Lake it forms bluffs 200 feet in height. The material is of homogeneous texture and is well bedded. No fossils are known to have been found in it. This material has been assigned by Russell[a] to a position overlying the basalt. When traced southward, however, it seems to pass beneath the lava of the plateau, and detailed study may show that it is interbedded with the upper portion of the basalt.

In a few other localities layers of fine-grained and well-bedded tuffs were seen, where they are exposed along bluffs, but the surface extent of the material at these places is not sufficient to warrant indicating it on the geologic map (Pl. III). Such beds were noted near Silver Lake, at the point of the bluff about 2 miles north of the Seventyone ranch, and on the north side of the canyon of Silver Creek, about 3 miles north of this point. At the former place the material is a soft, well-bedded, light-gray sandstone, of which a small amount has been quarried as a building stone. At the latter place there is exposed a thickness of 50 feet of the rock, which dips about 2° northward.

On the eastern edge of the county, where Swamp Creek joins South Fork of Malheur River, similar material is found at the bluff between the canyons of these two streams. The exposure is made prominent by a private road that cuts into the sandstone, and also by the face of a quarry that has been opened to obtain the material for building purposes.

[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903, p. 16.

MAIN LAVA FLOWS.

By far the greater part of the area over which the rocks are exposed is covered by lavas that are thought to belong to the same period of effusion as the Columbia River basalt. These rocks are mainly basalts and basaltic tuffs. There is much variation in texture and composition in the former, from hard black fine-grained varieties to coarsely crystalline rocks composed chiefly of basic feldspar; and in the latter from fine-grained homogeneous tuffs to coarse agglomerates. Associated with the basalts and in many places interbedded with them there are sheets of rhyolite and rhyolitic tuff, so that sections exposed in some escarpments show an alternation of basaltic and rhyolitic layers. About 2 miles northeast of Diamond the road to Happy Valley ascends a 350-foot bluff in which is exposed, from the bottom up, basalt along the border of the flat of Swamp Creek, white and light-colored tuffs for over half the way to the top, and over that a gray, glassy rhyolite, covered by a thin capping of basalt. On descending to Smith this series is crossed in reverse order, but on this eastern side of the plateau the tuff is much thinner and the lower basalt is met higher above the valley land. On the east side of Alvord Valley the road from Andrews to Whitehorse ranch climbs across a similar alternation of layers. The series at this place consists of basalt overlain by about 100 feet of rhyolitic tuff and rhyolite, and over this approximately 100 feet of tuffaceous sediments, covered by a thin layer of basalt.

The siliceous rhyolitic rocks were noticed principally in the eastern and northern portions of the county, where rhyolitic tuffs cover wide areas. On the northern and northwestern borders of the Harney basin the surface rocks are also mainly such siliceous varieties. The rim rocks back of Harney and the lower slopes on each side of Silvies River are composed of them. In the southeast also the rim rocks bordering the stream gorges near Diamond are of rhyolitic tuff, while on the eastern edge of the county great sheets of it cover the plateau that extends southward from Venator. The greater part of the more elevated masses of Steens Mountain, and of the hills draining to Malheur River, is composed of basaltic rocks, as is also the great expanse of plateau in the southwest. Siliceous rocks were noticed at numerous other points in these great areas, but basalt is by far the predominant rock.

Occasional dikes were seen that cut almost vertically through the flat lava beds. The most prominent of these are two parallel dikes of basalt which extend along the scarp of Steens Mountain, about two-thirds of the way toward its crest. The larger of these is very prominent throughout a great part of its exposed length, being 10 to 60

feet in thickness at places where it was seen at close range, and standing 50 feet or more above the slopes of the scarp. Its course was traced from a mile north of Whisky Hill to the most rugged portion of the scarp, northwest of the Alvord ranch, a distance of 17 or 18 miles. Of siliceous dikes perhaps the most notable one is on the eastern edge of Harney Valley, near the stage road to Vale. There a dike of white porphyritic rhyolite crosses a stream channel and forms what is locally known as the "reservoir site."

LATER ERUPTIVE LAVA.

Several miles northwest of Diamond there is an area of basaltic and scoriaceous lava surrounding craters from which it issued. This recent lava is but sparingly covered with thin patches of soil, though sagebrush has obtained a foothold over much of it. A number of the craters or cinder cones, which are built up of scoria and small bombs, still have their original forms, while numerous pressure ridges in the lava, near the edge of the flow, are also interesting features of the surface.[a]

The flat country that lies between Malheur Gap and the Mule ranch and extends to Indian Creek is covered with basalt that is raised into pressure ridges and otherwise much resembles the recent flow near Diamond, though it supports a heavier growth of sagebrush.

Malheur Cave is a low arched chamber in this basalt, between Camp and Indian creeks. It is said to be about a mile long, from 50 to 100 feet wide, and in places 20 feet high. The entrance to the cave is an opening about 25 feet wide and 4 feet high, at the end of a slight depression in the lava plain. The cave slopes gently downward toward the back, and the farther half of its floor is covered with water, which seems to be the accumulation from surface drainage and from seepage. This cave was possibly formed by cooling of the surface of the lava flow so as to make a crust, while the still molten inner portion flowed out from beneath it and left a long tube or tunnel. Caves of this character are common in other basaltic regions, and this theory of their origin has been spoken of by Russell and others.

An area of similar basalt covers the valley of Crane Creek from a mile or two below the mouth of Coyote or Little Crane Creek to near the mouth of Coleman Creek.[b] Possibly these two areas of basalt are parts of the same flow, their connection through the valley of Camp Creek now being obscured by alluvium. Although this lava is very probably of more recent age than the main flows, it is evidently older than that of the Diamond craters, and hence it is not classed with the latter on the geologic map (Pl. III). In other localities

[a] These craters and the surrounding lava have been fully described by Russell in Bull. U. S. Geol. Survey No. 217, 1903, pp. 54–56.

[b] This is also described by Russell in Bull. U. S. Geol. Survey No. 252, 1905, p. 37.

smaller areas of similar basalt were noticed that appear to be of later effusion than the main flows, and it may be that when the geology is studied in detail the extent of these later flows can be mapped and their sequence determined.

The succession of rhyolites and basalts and their associated tuffs forms a series the greater part of which is of middle Tertiary age; but the basalt flows in Anderson Valley and along Crane Creek, which are evidently of later date, and the comparatively recent craters near Diamond suggest that effusion has continued almost to the present.

VALLEY FILLING.

All the valleys are filled by silts and sandy deposits, which have given them their fine-grained coatings of soil. Records of the few deep wells that have been sunk in Harney Valley show that in its central portion the sediments consist chiefly of clays with a few interbedded layers of sand, while nearer the borders of the basin sandy and gravelly layers predominate.

Such a condition is found where streams bring down alluvial material and discharge it into lakes; for on entering the quiet water their currents are checked, and the coarser, heavier portions of their loads are deposited first near shore, while the finer material that is held longer in suspension is deposited farther out in more evenly assorted layers. Borings in Harney Valley show that these unconsolidated deposits are relatively shallow, probably in few places over 300 feet in depth, while structural conditions in Whitehorse and Catlow valleys indicate that in them the deposits are still less extensive. In the formation of the Alvord basin faulting and other deformation of the lavas have played such important parts that the position of the rock floor of the valley can not even be approximated from the evidence now obtainable. Wells have been bored south of Andrews to a depth of 200 feet without encountering firmer material than coarse gravel, and one drilled near its northern end by Mr. J. H. Neal to a depth of 435 feet did not reach solid rock.

The alluvium deposited directly by the streams merges so imperceptibly into the sediments that have been held longer in suspension in the lake water and finally laid down in more homogeneous strata that in many places the two classes of material can not be separated. Since the disappearance of the former lakes the wind has reassorted much of the finer material, transporting it from one locality to another and mixing with it residual soil from the plateaus, so that the records of deposition are still further obscured.

In some districts, however, areas covered by purely stream deposits still remain. On each side of the valley of Silver Creek above Riley, beyond the limits of the creek bottom, there is a belt of gravelly

bench land formed of stream wash. Similar beds of gravel border the western side of Warm Spring Valley along Malheur River, in the northeast corner of the area examined. On the western side of Alvord Valley numerous short streams from Steens Mountain have brought down quantities of gravel, and have built up large alluvial fans that extend far into the lowland. Between Mann and Juniper lakes the amount of material brought down has been sufficient to form a low alluvial divide across this narrow part of the valley, which separates and probably has also formed these two small lake basins. In Catlow Valley, Home and Threemile creeks have built extensive alluvial fans where they debouch into the lowland, while Skull Creek has formed similar deposits where its narrow valley opens to the broader plain. Nearly all the streams entering Harney Valley have such low grades that they have not built noticeable alluvial deposits. Instead, the finer valley sediments extend for some distance within their canyons and form stretches of meadow land bordering the stream channels.

GEOLOGIC STRUCTURE.

Since the outpouring of the great sheets of lava that now cover most of this region, movements in the earth's crust have disturbed them and altered the surface features. In some places the rocks have been bent into great low folds; in others immense blocks have been broken loose from adjacent parts of the crust and uplifted or depressed. By these movements and dislocations valley basins have been formed and escarpments have been produced that are now prominent features in the topography.

The most notable structural feature in southeastern Oregon is a great uplift, the western portion of which forms Steens Mountain. Bordering the western side of Alvord Valley a great fault extends, along which the movement took place that formed the escarpment of this mountain. On the opposite side of the valley lower escarpments and the gentle eastward inclination of the rocks show that the major structure is that of a great arch or anticline. This has been broken, and its central portion, or the keystone of the arch, has been dropped. It is upon this faulted block or keystone that Alvord Valley lies, bordered on each side by the escarpments that were produced by the dislocation. The maximum displacement of this faulting is attained west of the Alvord ranch. At this locality the height of the rim rock above the valley shows a displacement of fully 5,000 feet, but how much this is increased by the depth of the rock floor below the valley surface is at present only conjectural. The hills that rise from the valley floor seem to be tilted blocks that were broken off and displaced by the movement that produced the greater topographic feature. The ridge between Wildhorse Creek

and Alvord Desert may be a great splinter that was partially left behind in the uplift along the major scarp, while a similar smaller block clings to the side of the bluffs west of Mann Lake.

Although the lavas have been more or less disturbed over all this country, and have been bent into arches and troughs, few dips greater than 15° were seen, while most of the beds are inclined at angles of less than 10°; thus the folding is characterized by low broad structures. The Harney basin is the largest of these low folds, being in effect a great shallow depression in the plateau, 50 miles or more in diameter. The several buttes and ridges within it show that it is not a simple saucer-like basin, but its synclinal form is the major structural feature of the central part of the county. Whitehorse and Catlow valleys also lie in basins that seem to be shallow synclinal troughs. The structure of the Catlow basin is not so clear as that of Whitehorse and Harney valleys, for an escarpment borders its eastern side, which in its highest portion rises 1,400 feet above the plain, while another cliff 400 feet high extends for several miles along the northeastern end of the valley. These escarpments are thought to have been produced by erosion and weathering rather than by faulting, however, and the reasons for this assumption are given later in the discussion of Catlow Valley (p. 68). The upper part of the course of Donner und Blitzen River has been mentioned by Russell[a] as being in a plunging synclinal trough. Along the middle course of this river, between the P ranch and the Buena Vista ranch, this fold seems to develop into a fault, for an escarpment that attains a height of over 1,000 feet forms the western side of the valley. Northward this scarp dies out in the nearly horizontal beds of the plateau land. An escarpment that borders the eastern side of Warner Valley exceeds a height of 2,000 feet for a great part of its length, and is very probably the face of a fault block.

Not all the scarps of the Harney basin region are of fault origin, however. Those of Catlow Valley have been mentioned as probably the results of erosional forces, and Harney Valley is bordered in part by scarps 100 to 400 feet high, which are evidently due to such agencies. In this connection it may be stated that the rocks dip gently away from the scarps of Steens Mountain, of Warner Valley, and of Donner und Blitzen River, which have almost undoubtedly been produced by faulting, while the dip is toward the escarpments bordering Catlow and Harney valleys. It is not to be understood that this is a distinctive difference between scarps of erosional and those of fault origin, but it is characteristic of the tilted block structure.

[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903, p. 15.

On the northern side of the canyon of Trout Creek, from about 2 miles west of Flagstaff Butte to the mouth of the canyon, there is exposed a thickness of several hundred feet of greenish rhyolite, while the hills south of the creek are mainly basaltic. This fact, taken together with the attitude of the rocks, suggests that there has been some faulting along the course of this canyon, although there are no marked topographic features to confirm the suggestion.

The mountains north and northwest of Harney Valley are anticlinal in structure, as are other smaller uplifted masses in the area examined. All the minor features that have been mentioned, however, are subsidiary to the two great structures that dominate the deformation in southeastern Oregon, namely the Steens Mountain uplift and the wide shallow depression of the Harney basin.

The structure is shown in a general way on the geologic map (Pl. III) by heavy black lines that follow the major faults, and by red lines along the axes of the principal folds that were noticed. There are also dip symbols indicating the general inclination of the lava beds in other portions.

PHYSIOGRAPHY.

TOPOGRAPHIC CHANGES.

Concerning the surface of this country previous to the outpouring of lava that spread over southern Oregon and adjacent portions of Idaho and Nevada, it is known only in a very general way that it was carved into mountains and valleys that formed a well-developed topography. The floods of Miocene lava buried this preexisting topography hundreds and in places thousands of feet deep, and filled up canyons and valleys; so that at the cessation of the period of greatest volcanic activity the surface was that of a vast, nearly level plateau. Farther north the Strawberry Mountains and other large uplifted masses were surrounded but probably not buried by the lava, and still gave some diversity to the surface. Within the southern portion, however, only a few isolated peaks, such as Iron Mountain and Flagstaff Butte, were left projecting above the otherwise slightly undulating surface.

DEFORMATION.

At a later time earth movements began that resulted in the uplift of the Cascade Mountains. Although this range is 150 or 200 miles west of Harney County, the forces that produced it were felt at this distance, and disturbed the relatively level surface. In some places low ridges and shallow basins were produced, while in others the plateau surface was broken into great blocks, having their long axes extending in general from north to south. By unequal subsidence in some places and by uplift in others these were tilted and now

form elevations having an escarpment on one side and a gentle slope on the other. From its extensive development in the Great Basin, and since its study by Gilbert and Russell, this has become known as the basin-range type of structure. Within the area covered by this report, the escarpments of Steens Mountain, of Donner und Blitzen River, and of Warner Valley have been said to be probably of this origin. Aside from these three major fault lines the present topography seems to have been produced mainly by gentle deformation, which produced the Harney basin and other smaller areas of depression, and by low upfolding, which formed the hills to the north and northwest.

PRESERVATION OF LATER TOPOGRAPHY.

The main features of the topography that resulted from this deformation still exist comparatively unmodified. The escarpments are still clear cut, the gentler slopes are dip slopes, and the minor folds are little altered by erosion. The plateau areas indeed appear to be approximately the original surface so far as removal of material by erosion is concerned. This unmodified condition indicates that deformation can not have taken place very long ago, geologically speaking, else weathering and erosion would have succeeded in wearing down the slopes more than they have, for the rainfall was greater during the Pleistocene epoch than it is at present; hence within geologically recent times the erosive action has been much greater than it is at the present day. It would even seem that slight movements have continued nearly to the present time, if a small scarp in the alluvium at the west edge of Alvord Desert be considered a fault scarp.[a]

EROSIONAL AGENCIES.

STREAM ACTION.

The work of erosion has nevertheless carved prominent though secondary topographic forms in the mountains and plateaus. In the higher portions of Steens Mountain, where rain and snow are more abundant than in the lower land, deep gorges have been formed. It is by such stream action that the notches have been cut through which Home Creek, Threemile Creek, and Skull Creek descend from the higher to the lower plateau; that the gorge of the northern branch of Donner und Blitzen River has been formed; and to a certain extent, also, that the precipitous canyons on the eastern face of Steins Mountain have been eroded.

A minor feature that was noticed along several streams is perhaps best exhibited on Smith Creek, where a number of meadows have been formed along its course, which are separated by small gorges

[a] Russell, I. C., A geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, p. 445.

that have been cut through low basalt folds. These folds are transverse to the stream course, and it seems as if they have been produced since the establishment of the drainage line, and that the stream has cut down through them as they rose, but not rapidly enough to keep its channel cut to grade. The checking of the water and the consequent deposition of silt behind the low barriers produced the present stretches of meadow land.

GLACIATION.

In the highest part of Steens Mountain there is some evidence in the topographic forms that there has been a small amount of glaciation. The gorge of Kieger Creek in its upper 4 or 5 miles is 1,500 feet or more in depth, somewhat U-shaped in section, with small hanging valleys on its western side; and it heads in a deep cirque nearly half a mile across. Beneath the north-facing cliffs there are snow banks that remain throughout the year. In one of his later papers Russell gives a detailed description of this gorge and discusses its possible origin by ice action. Concerning it he says:[a]

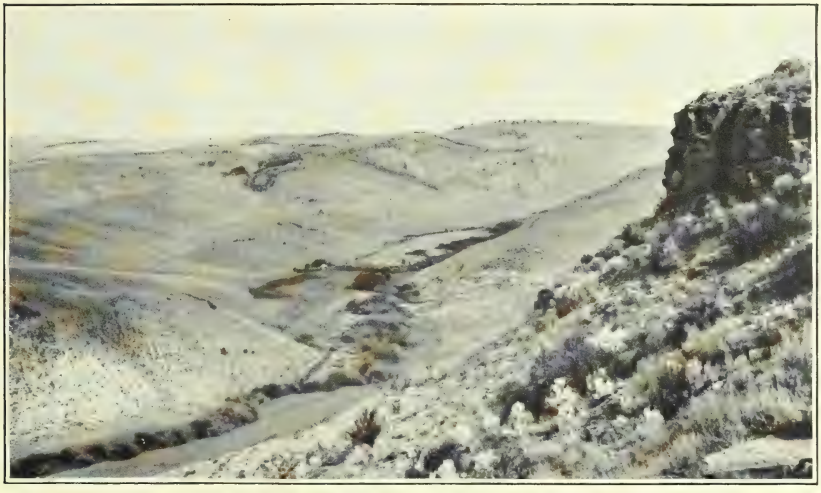
> Kieger Canyon is prolonged for some 20 miles below the locality where the lowest evidence of glaciation is discernible, and is not floored with coarse débris, such as occurs downstream from the extremities of existing valley glaciers. No alluvial terraces are present to show that conspicuous variations in the load of Kieger Creek have occurred, such as are present in many valleys which have held glaciers in their higher tracts. There are no recognizable terminal moraines anywhere in the canyon and almost a complete absence of lateral moraines. The evidence of the former presence of a glacier in the upper end of the canyon is furnished principally by a noticeable increase of width in the portion formerly occupied by ice and a change from nearly vertical walls to a U-shaped cross profile. * * * The facts presented by Kieger Canyon * * * are consistent with the idea that a deep water-cut trench existed before the glaciers from the south entered it, and that it has experienced what may be termed a "small degree of glacial erosion." This conclusion finds support also in the fact that, so far as has been discovered, none of the other canyons on the Steen Mountains show evidence of glaciation. Kieger Canyon stands in the highest portion of the upturned block in which it has been excavated, but the advantages thus assured in reference to snow accumulation are not conspicuous. Seemingly the conditions were so delicately adjusted that a glacier was formed at the head of Kieger Canyon, but not in the neighboring canyons. This condition of delicate adjustment of elevation and topographic conditions to the climate of the region is now manifest by the presence of perennial snow banks in the shelter of northward-facing cliffs on the border of Kieger Canyon and their absence on the borders of the neighboring canyons.

WEATHERING.

The processes of weathering and decay have been efficient in forming many escarpments, especially along the valley borders. It is thought that the bluffs back of Harney and the escarpments of Wrights Point and of Windy Point are of such origin. In these scarps the forms produced by the weathering of nearly horizontal beds overlying softer tuffs is ideally developed. In Plate IV, *A*, is

[a] Russell, I. C., Hanging valleys: Bull. Geol. Soc. America, vol. 16, Feb., 1905, pp. 84–85.

A. CHARACTERISTIC SCARP AT WEST EDGE OF HARNEY VALLEY.



B. VALLEY OF RATTLESNAKE CREEK ABOVE HARNEY.

shown a portion of the scarp about 8 miles west of Wrights Point, in which the abrupt transition from level alluvial valley land to flat rocky plateau is well exhibited.

Within the Harney basin the channels of several streams are intrenched between escarpments that seem to be as much the result of weathering as of direct stream cutting. Of such character are the courses of Silvies River above Burns, of Kieger Creek for 6 miles above Diamond, of Rattlesnake Creek near Harney, and of Camp Creek from near Malheur Cave to the valley of South Fork of Malheur River. Low grades and the consequent formation of strips of meadow land that extend far up their courses are also characteristic of these streams. The meadow along the course of Rattlesnake Creek is shown in Plate IV, *B*. It may be that such a strip of meadow is the result of the cutting of the stream nearly to its base level, the level of Harney and Malheur lakes; but in some respects this feature resembles that produced by the drowning of stream mouths. Russell[a] has shown that Silvies River formerly flowed through Malheur Gap and thence to Malheur River. A flow of basalt, probably during the Pleistocene epoch, certainly since the formation of the Harney basin, closed this outlet, produced a great shallow lake, and allowed the basin to be silted up. This may have been the cause of a reduction of the stream grades and the formation of the present meadow lands.

LAKES.

The lakes of southeastern Oregon are very good examples of the dependence of such bodies on the climate for their existence. During the Pleistocene epoch the basins that were produced by earlier deformation of the lavas were occupied by water bodies many of which have left evidence of their extent in slight terraces or water lines along the valley sides. No less than four well-marked and two fainter lines on the eastern side of Alvord Valley show that a lake of varying size once occupied it, and that the water attained a maximum depth of over 100 feet above the present valley floor.[b] In Catlow Valley three well-marked water lines persist along the entire eastern side of the basin and show that water to a depth of over 75 feet once covered it. In the basin of Warner Lake similar high-water marks are to be seen. Even in the small basin of Juniper Lake there are two shore lines, respectively about 30 and 60 feet above the present lake surface. In the largest basin, that of Harney and Malheur lakes, no such record is noticeable, probably because of the shallowness of the ancient lake; but the character of the deposits throughout its extent shows unmistakably that they are of lacustrine origin.

[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903, p. 22.

[b] In the Fourth Ann. Rept. U. S. Geol. Survey, 1884 (p. 459), Russell assigns a depth of 400 feet to the former lake in this valley, but the evidence for it is not given.

In regions where precipitation is ample to supply the losses by evaporation and possible leakage a lake is a fairly permanent feature; where the balance between gain and loss swings now to one side, now to the other, the lake area fluctuates; and where the annual supply does not equal the loss, only playas or intermittent lakes can exist.

In this region Harney Lake is the best example of a water body where the first-named conditions obtain, partly because it occupies a deeper basin than the others, where evaporation does not cause so marked changes in area, and partly because it draws upon its neighboring lake to supply its own losses. For this latter reason Malheur Lake is an exceptionally good example of a fluctuating water body, for its area is affected not only by the evaporation from its own surface, but from that of Harney Lake as well. Since its shores slope very gently the seasonal variation of its surface causes marked change in its extent. Warner Lake is also a fluctuating one; though if evidence is correct that has been advanced in lawsuits over land acquired in its valley under the terms of the swamp-land act, this water body, which is broken into a number of lakes during the summer time, has been shrinking during late years. Alvord Desert is the largest of the many playas or beds of temporary lakes in this region. In summer it is a dry, barren area; in winter and early spring the melting snow and the water from the adjacent slopes render it a slippery mud flat. During wet years it receives overflow water from Alvord Lake. In the spring of 1882 it is said to have been thus covered to a depth of 7 inches.

SURFACE WATER.

DIVISIONS.

The portion of southeastern Oregon that is shown on the reconnaissance map (Pl. II) may be divided into eight hydrographic basins or drainage areas, if the central plateau region of indefinite drainage, in which there are many small depressions that contain playas, be considered in this respect as a drainage area. In discussing the surface-water supply, the streams and springs of each basin will be taken up in turn, and on pages 39–41 the stream measurements that were made during the field work are tabulated according to their several drainage basins. The discharges of Silvies River and Silver Creek, which were computed from records obtained at the official gaging stations, are given on pages 31 and 34, respectively.

HARNEY BASIN.

AREA AND EXTENT.

The Harney drainage basin comprises about half the area of Harney County, and extends from the south end of Steens Mountain northward to the base of the Strawberry Mountains, in Grant

County. On the east its limit is well marked by hilly divides, but in the plateau to the west and southwest its boundary is not so definite. From the northern timbered portion of the county there is considerable run-off; in the south, too, the slopes of Steens Mountain supply a number of streams. The central portion is occupied by Harney Valley, a wide, flat area in which lie Malheur and Harney lakes, and into these the greater part of the drainage of Harney County discharges.

STREAMS.

Silvies River, one of the main streams of this basin, has its source in streams that rise at the base of the Strawberry Mountains, just south of the divide that at this point marks the northern limit of the Great Basin and the beginning of drainage to John Day River. Emigrant Creek, which drains a part of the mountains northwest of Burns, joins Silvies River about 15 miles above this town. Throughout most of its course the river is a sluggish stream. Between Bear Creek Valley and Silvies Valley, and also at the lower end of the latter valley, it cuts through several miles of rocky canyon; but within the valleys it forms wide areas of meadow land. In its lower course, in the vicinity of Lawen, the water reaches Malheur Lake through a number of sloughs and drainage canals. From May 10, 1903, until July 24, 1906, daily gage readings were recorded on this stream at two stations under direction of the U. S. Geological Survey. The upper station was near Silvies, above the mouth of Emigrant Creek. At the lower station, near Burns, the total flow of the stream was recorded. The monthly discharge, estimated from the records that were obtained at this station, is tabulated below.

Estimated monthly discharge of Silvies River, near Burns, Oreg.

[Station established May 10, 1903; discontinued July 24, 1906. Figures give total flow in acre-feet.]

Month.	1903.[a]	1904.[b]	1905.[c]	1906.[d]
January		1,476	[e] 1,608	1,320
February		16,390	[f] 500	1,370
March		48,640		4,770
April		146,400	[g] 17,800	75,000
May	[h] 13,702	64,990	12,600	25,600
June	6,010	12,560	4,391	25,500
July	1,414	3,080	1,408	[i] 3,130
August	492	1,347	627	
September	[j] 129	970	542	
October	246	1,857	861	
November	2,321	1,964	1,101	
December	[k] 1,031	1,888	965	
		301,600		

[a] From Water-Supply Paper U. S. Geol. Survey No. 100, 1904, p. 433.
[b] From Water-Supply Paper U. S. Geol. Survey No. 133, 1905, p. 351.
[c] From Water-Supply Paper U. S. Geol. Survey No. 176, 1906, p. 124.
[d] From Water-Supply Paper U. S. Geol. Survey No. 212, 1908, p. 83.
[e] For 17 days.
[f] February 1 to 6, inclusive.
[g] April 9 to 30, inclusive.
[h] May 10 to 31, inclusive.
[i] July 1 to 24, inclusive.
[j] September 1 to 12, and 17.
[k] December 1 to 26, inclusive.

On the south side of the Harney basin a number of streams rise in Steens Mountain and flow toward Malheur Lake. Nearly all of these are tributary to the trunk stream, Donner und Blitzen River, though much of their water sinks in the marsh of the lowlands before reaching that river. The streams will be mentioned in order, beginning at the south and proceeding northward.

Donner und Blitzen River, the largest of the Steens Mountain streams, and the one to which the others are tributary, rises in the southern part of this great block, and after flowing in a direct course northwestward for 25 or 30 miles enters the lowland near the P ranch. Thence it continues as a sluggish stream, in some places through a number of sloughlike channels, the remaining 30 miles or more to Malheur Lake. No records of its flow have been kept, but a careful float measurement that was made in August, 1907, at a point about $1\frac{1}{4}$ miles above the P ranch and one-fourth mile above the mouth of its canyon, before its water enters the marsh land, indicated a discharge of approximately 45 second-feet. When compared with the discharge of Silvies River above Burns during the same month, this measurement indicates that Donner und Blitzen River is much the larger stream at that season of the year; though it may be that it reaches its greatest flow later than Silvies River. In its lower portion the current of Donner und Blitzen River is too sluggish to admit of even approximate float measurement, but about 5 miles above the point where it is joined by Kieger Creek, a stream that brings considerable water from the southeast, a rough weir measurement indicated a flow of about 55 second-feet, or somewhat less than the sum of the flow near the P ranch and that of the two tributary streams, Bridge and Krumbo creeks.

Mud Creek rises near the crest of Steens Mountain, north of the upper branches of Donner und Blitzen River. Near the head of its drainage basin its channel is not well established, and there are several small lakes and marshy glades. The upper course of the stream lies along a narrow swale that is lightly timbered with cottonwoods, but below the lower limit of these trees, which is at an elevation of about 6,000 feet, the stream has cut a gorge in the basalt slopes. Through this it continues westward to the marsh of Donner und Blitzen River. It is not a large stream, for although it flows from the higher lands it has few tributaries. During the summer its upper course is nearly dry, while at its entrance to the marsh land the flow is only 10 or 15 miner's inches.

Bridge Creek joins Mud Creek at the edge of the marsh land along Donner und Blitzen River. It is only a few miles in length, and its grassy bottom and large flow, about 12 second-feet, indicate that it is supplied by constant springs of large volume. A couple of miles

north of this creek springs rise that yield a flow of 80 or 90 miner's inches, but the water barely reaches the edge of the marsh.

There is a wide stream channel 3 miles north of Bridge Creek, but it was dry in August, 1907, and seemed mainly a flood-water channel.

Krumbo Creek, at the point where the road between the Diamond ranch and the P ranch crosses it, was carrying about 5½ second-feet of water in August, 1907. Above this point its canyon is narrow and is cut perhaps 100 feet below the plateau surface; below where the road crosses it, the stream flows through meadow land to the marsh of Donner und Blitzen River. This creek also probably is supplied largely by springs, for its drainage area does not warrant so great a summer flow.

McCoy Creek rises near the head of Mud Creek, in a wide swale, and flows north and northwest in a well-developed canyon to the foot of the mountain slope. In its upper portion this canyon is 300 to 500 feet deep. It has steep but not precipitous sides, and cottonwoods grow along the banks of the creek. In its lower portion the canyon walls are cliffs not much over 100 feet in height, between which the stream flows in a flat-bottomed meadow 100 yards wide. Through this it maintains a fair grade until it reaches the marsh land. Along the sides of its canyon numerous springs rise and materially increase the flow of the creek. The discharge of McCoy Creek, when roughly measured in August, 1907, about 2 miles above the Diamond ranch, was about 3½ second-feet.

Cucamonga Creek lies upon the strip of plateau between the nearly parallel canyons of McCoy and Kieger creeks. For most of its length its channel follows a wide gentle swale, but about 4 miles above the Diamond ranch it has cut down into the rocks and drops 300 feet in less than a mile. Thence it meanders to the marsh through meadow land bordered by cliffs. Its summer flow is small, being only 10 or 15 miner's inches.

The upper course of Kieger Creek, the next stream to the north, has been well described by Russell, whose words are quoted on page 28. From the junction of the two branches of this creek, 6 miles above Diamond, to the open marsh, the stream meanders along a channel thickly overhung with willows and other water-loving bushes, through a strip of meadow similar to that of McCoy and Cucamonga creeks. Its measured summer flow was about 9 second-feet.

Swamp Creek, near Diamond, is a small stream that flows during only a part of the year. In summer it is dry along its lower course, but water is usually to be found in its upper portion.

The last four streams that have been mentioned enter the marsh land that extends southeastward to Diamond, and flow through it

in several natural channels and in drainage canals to join Donner und Blitzen River.

Smith Creek and Riddle Creek unite in Happy Valley, which is 8 or 9 miles northeast of Diamond, and flow northward and westward to Barton Lake. This lake is a long narrow water body that was probably formed by the damming of the stream course by the lava from Diamond Craters. The lake varies much in size with the season, and while there is no present surface outlet, the spring overflow water is locally believed to reach Malheur Lake through an underground channel. A deep crack in the basalt, a foot or two in width at the surface, at the western high-water line of the lake is locally considered to be the entrance to this channel. The summer flow of the two streams that unite to supply this lake varies with the amount of water that is taken out for irrigation along their upper courses. In August, 1907, the flow at the wagon bridge a mile east of Barton Lake was about 60 miner's inches, but in October the flow was only about half this amount.

Silver Creek is the larger of the two streams that enter Harney Valley on its western side. It drains the southwestern slopes of the mountains north of Riley. After emerging from its canyon approximately 15 miles above this place, it flows in a general southeasterly course to Harney Lake. Within its canyon it is a perennial stream of considerable flow, but it usually becomes dry below Riley, in early summer. From the head of the valley of Silver Creek to Harney Lake, its channel has a gentle grade and extends through alluvial land nearly the entire distance. During 1904 and parts of 1905 and 1906, daily gage readings were noted on this stream near the mouth of its canyon, under the direction of the U. S. Geological Survey. The monthly discharge as computed from these readings is tabulated below.

Estimated monthly discharge of Silver Creek near Riley, Oreg.

[Station established April 19, 1904; discontinued July 14, 1906. Figures give total flow in acre-feet.]

Month.	[a] 1904.	[b] 1905.	[c] 1906.
January	615	3,616	.....
February	1,150	2,327	2,150
March	27,670	7,870	5,690
April	55,640	6,545	25,900
May	12,670	3,136	5,070
June	2,303	922	7,320
July	3,333	.....	[d] 805
August	357	.....	.....
September	155	.....	.....
October	141	.....	.....
November	369	.....	.....
December	885	.....	.....
	105,300	.....	.....

[a] From Water-Supply Paper U. S. Geol. Survey No. 133, 1905, p. 354. Discharge estimated January 1 to April 14 and July 17 to September 9, inclusive. During latter part of year, gage heights estimated for missing days.

[b] From Water-Supply Paper U. S. Geol. Survey No. 176, 1906, p. 127. Records fragmentary after July 8, as there was no regular observer. Creek was dry in August, September, and the greater part of July.

[c] From Water-Supply Paper U. S. Geol. Survey No. 212, 1906, p. 85.

[d] July 1 to 14, inclusive.

The spring flood water from this creek spreads over and irrigates many acres of natural hay land along its lower course, and also supplies Silver Lake.

Sagehen Creek, the other stream that enters Harney Valley from the west, joins West Fork of Silvies River about 8 miles south of Burns. Its summer supply comes mainly from springs that rise along lower Cold Spring Creek and in the marsh land below the mouth of this stream. Through this saturated ground Sagehen Creek is a sluggish stream of which no satisfactory measurement could be made. In the lower portion of Willow Creek, a tributary to its upper course, a little water was standing during the summer of 1907, but there was no appreciable flow.

Along the northern and eastern sides of Harney Valley there are a number of small streams that flow during only a part of the year. Of these, Rattlesnake Creek, just east of Harney, is the largest. Its bed was dry near Harney in August, 1907, but 3 miles above this town it was flowing about 20 miner's inches.

SPRINGS.

Within Harney Valley there are a number of springs that from their size and the constancy of their flow may properly be mentioned here. Of these, the springs in Warm Spring Valley, at and near the Double O ranch, have by far the greatest flow. Eight springs rise in this lowland west of Harney Lake, the six largest of which issue at the base of bluffs that border the south edge of the valley. Their water is noticeably warmer than that of the shallow wells of the region. The combined flow of the largest springs, which are near the Double O ranch house, is 25 or 30 second-feet. The character of these springs and their significance in respect to underground water conditions will be discussed in speaking of artesian possibilities in the Harney basin.

At Sodhouse, 6 miles east of Narrows, there is a spring similar to the springs of Warm Spring Valley. The water issues at the base of a low hill, where it forms a pool about 75 yards across, and joins Donner und Blitzen River in the marsh land bordering Malheur Lake. An approximate summation of the flow from the many small streams that issue around the border of this pool is 100 miner's inches, while several springs that rise within it probably increase the total flow to twice or three times this amount.

Springs similar to those just described issue at two points from the base of a hill about 3 miles south of Burns. From these two localities a constant flow of about 30 miner's inches is supplied to the marsh land. Of like character are the springs along Sagehen Creek, which have already been mentioned. These rise in the marsh land of its lower course and greatly increase the flow of the stream.

CATLOW BASIN.

STREAMS.

In the southern portion of the plateau lying southwest of the Harney basin the run-off water drains toward Catlow Valley, as the lowest portion of the basin in the southern part of the county is called. The longest stream channel within the Catlow basin is that of Rock Creek, which rises at the northern base of Warner Mountain and flows northeastward. Water flows to the sink of this stream only until early summer. In September, 1907, a flow of 20 or 25 miner's inches reached Steve Young's, on its upper course, near where the road to Plush crosses the creek, but below this point there were only a few pools along its channel.

On the east side of the basin three streams, Home, Threemile, and Skull creeks, which rise in the slopes of Steens Mountain, flow westward to the valley land, in which their waters sink. The two former supply a shallow lake that lies well out on the valley floor.

SPRINGS.

At Roaring Springs ranch, on the east side of the basin, a constant flow of water issues from a number of springs part way up the bluff, and irrigates the meadow it has produced on the edge of the lowland. A number of similar springs, but of smaller flow, have formed another patch of meadow land farther south, at the HL ranch.

The total summer flow of the three creeks and two groups of springs on this side of the valley is between 15 and 20 second-feet. The discharge of the several streams is given on page 40.

ALVORD BASIN.

STREAMS.

For convenience in discussing its drainage the great sunken area that extends along the eastern base of Steens Mountain will be termed the Alvord basin. This consists of several minor lake basins, but structurally it is a single depression or basin.

In the Alvord basin a number of small streams that are supplied by melting snow from Steens Mountain cascade down its escarpment to the lowland. The largest quantity of water, however, comes from the southeast through Trout Creek, which furnishes the main supply of Alvord Lake. This stream rises near the southeastern corner of Harney County, and drains a considerable area of upland in the Whitehorse Mountains and Trout Creek Hills, which furnish it a perennial supply. There are two smaller lake basins, those of Juniper and Mann lakes, which also lie within the Alvord basin, but are separated from the drainage to Alvord Lake by low alluvial divides. Mann

Lake receives its supply principally from the mountain stream entering its southern end, while Juniper Lake is supplied chiefly by a similar stream that enters it from the north.

SPRINGS.

Within the Alvord basin there are three springs whose flow is sufficient to warrant mention in connection with the surface water supply. The largest of these is a hot spring at the borax works south of Alvord Lake. Here a pool about 275 yards in diameter has been formed around several vents at this place, and a nearly constant flow of about 100 miner's inches is discharged through a ditch on its western edge. From one-quarter to one-half mile north of the borax works there are a number of other hot springs, which yield a considerable supply of water, but one whose quantity is hard to determine, for there is no well-defined stream channel, but rather a series of pools from which the water rapidly sinks again into the alluvium. On the western edge of Alvord Desert there is another hot spring, which yields about 15 miner's inches. The third and perhaps the most valuable spring in this basin, because of the quality of its water and its favorable location for purposes of irrigation, is that near Serrano Point, southeast of Andrews, on the ranch of Mr. A. C. Bustamante. This yields a constant flow of about 25 miner's inches of water.

WHITEHORSE BASIN.

On the southeastern edge of Harney County, east of the Alvord basin, there is a shallow basin in which lie Willow and Whitehorse creeks. Both of these streams rise in the Whitehorse Hills and flow in a direct course northward to their common sink. Willow Creek is much the larger, having a flow of about 70 miner's inches in September, 1907, while Whitehorse Creek at this time carried only about 10 inches.

MALHEUR RIVER DRAINAGE.

The mountains east of the Harney basin are drained by a number of small intermittent streams that are tributary to Malheur River. Crane Creek is the largest of these, and to it the other streams of this part of the watershed are tributary. In its lower portion it is known as South Fork of Malheur River. It rises near the eastern edge of the Harney basin, flows south, then swings through an easterly to a northerly course, and joins Middle Fork of Malheur River near Riverside. In August, 1907, Crane Creek was dry in the valley of its upper course, but about 5 miles below this valley a stream of 5 or 10 miner's inches was flowing. All of its tributaries were dry or nearly so in their lower courses. The area that is drained by Camp and Indian creeks is tributary to Crane Creek, but during the summer

there is no surface accession to the latter stream from this southern area. The flow of the two streams is consumed in irrigating a belt of hay land between their junction and Venator post-office.

The main summer supply to South Fork of Malheur River is from several springs that rise close to its banks. The largest of these is at Mr. Chris Dennean's, about a mile above the mouth of Coleman Creek, where a large spring rises within a few yards of the river channel. A careful float measurement of the stream flowing from it indicated a discharge of nearly 200 miner's inches. Near this spring two small flows issue from the opposite bank of the river, while a few hundred yards downstream another spring contributes about 25 miner's inches. Near the mouth of Swamp Creek two similar springs add 30 or 40 inches more to the flow of the river. Perhaps 7 or 8 second-feet represents the approximate summer flow of South Fork of Malheur River, where it turns eastward and crosses the county line.

WARNER LAKE DRAINAGE.

In the portion of the Warner Lake basin included in the area mapped on Plate II there are no perennial streams. Mule Spring is an old well dug in the dry bed of a canyon, near the northern end of this basin, along a former military route. From its neighborhood a flood-water channel trends southward to the lake. Other similar channels carry part of the spring run-off from this region, but during the later months of the year water is lacking over most of the basin

PLATEAU REGION.

In the area lying between Harney and Warner lakes, which may be termed the plateau region, the drainage is only slightly developed. There are no perennial streams and few well-defined water courses within it. A wide coulee-like depression, along which the road passes between Buzzard Canyon and Mule Spring, contains a succession of playas that are collecting basins for the melting snow and the scanty rainfall, but no well-defined drainage channel has been cut along its bottom. Buzzard Canyon contains a more definite channel, which is tributary to Harney Valley, and during the spring run-off it carries some water to the alkaline flat east of Iron Mountain. For the most part, however, the drainage of this plateau is separated into a number of small basins such as that in the lowest part of which Walls Lake is situated.

GUANO LAKE BASIN.

The valley of Guano Lake was not visited by the writer, and little can here be said of its drainage except that Warner Creek, which rises near Warner Mountain, is the principal stream of the basin, and that this stream is dry in its lower course during the summer months.

TABLES OF FLOW.

The streams and springs that were visited and measured during the reconnaissance have been tabulated below, that some idea may be obtained of their relative size and of the amount of water that is available. These are but single measurements, mostly rough approximations by the float method, and were made at a season when many of the steams are at their lowest stage; but in the absence of better data they are all that can be presented at this time in regard to the surface water supply of the region. The discharges of Silvies River and Silver Creek, the only two streams on which systematic measurements have been made, are given in an earlier part of this paper (pp. 31, 34). The locations of the several springs, and the points at which the streams were measured, are shown on Plate III.

Estimates of flow in the Harney basin region, Oregon, during the summer of 1907.

HARNEY BASIN.

Number.[a]	Date, 1907.		Temperature.	Discharge. Second-feet.	Miner's inches.[b]
		STREAMS.	° F.		
101	August 3	Rattlesnake Creek, 3 miles above Harney		0.4	20
102	August 26	Smith Creek, at wagon bridge, 1 mile east of Barton Lake.		1.2	60
103	November 1	Donner und Blitzen River, 3 miles south of Buena Vista ranch.		55	2,750
104	August 28	Donner und Blitzen River, 1¼ miles above the P ranch.		45	2,250
105	August 30	Mud Creek, near mouth of canyon		.3	15
106	do	Bridge Creek, at mouth of canyon		12	600
107	August 27	Krumbo Creek, at road crossing		5.5	275
108	do	McCoy Creek, 2 miles above Diamond ranch		3.5	175
109	August 25	Cucamonga Creek, at head of its meadow		.3	15
110	August 24	Kieger Creek, 1 mile above Diamond		9	450
		SPRINGS.			
201	August 16	3½ miles northwest of Burns	52		1
202	do	1 mile west of Burns (M. L. Lewis, owner)	56		2
203	August 17	3 miles south of Burns	78 to 80	.2	10
204	do	3¼ miles south of Burns	78	.4	20
205		Along Sagehen Creek		[c] 2	[c] 100
206	August 13	2 miles north of Harriman	[d] 122	.4	20
207	August 5	North side of Crane Creek Gap			1±
208	August 18	Sec. 29, T. 25 S., R. 31 E.; developed spring (Mr. Newell, owner).			1
209	August 17	Sec. 7, T. 25 S., R. 31 E.(developed)	52		No flow
210	August 18	4 miles west of Dog Mountain (Mr. Weaver, owner)	51		2
211	July 28	At southern edge of Silver Lake	68	.1	5±
212	do	3½ miles east of Iron Mountain	68		1±
213	July 29	3 miles northwest of the Double O ranch			1±
214	August 20	At the Sodhouse, 6 miles east of Narrows	53 to 56	4 or 5	200 or 250
215	July 29	½ mile northwest of the Double O ranch	56	[c].6 or .8	[c]30 or 40
216	July 30	1 mile west of the Double O ranch	69	12.5	625
217	July 29	½ mile northeast of the Double O ranch (sum of flow of two canals).	72	20	1,000
218	do	1 mile southeast of the Double O ranch	67 to 73	4	200
219	do	1¾ miles southeast of the Double O ranch	72	2	100
220	do	2½ miles southeast of the Double O ranch		.1 or .2	5 or 10

[a] These numbers correspond to the numbers on Plate III.
[b] The miner's inch used here is 9 gallons a minute, or $\frac{1}{50}$ second-foot.
[c] Estimated.
[d] This is the temperature given by Russell, Bull. U. S. Geol. Survey No. 252, p. 41.

Estimates of flow in the Harney basin region, Oregon, during the summer of 1907—Con.

HARNEY BASIN—Continued.

Number.	Date, 1907.		Temperature.	Discharge. Second-feet.	Discharge. Miner's inches.
		SPRINGS—continued.			
			° F.		
221	July 29	3 miles southeast of the Double O ranch	68	0.5	25
222	....do	4 miles southeast of the Double O ranch		.9	45
223	August 19	½ mile southeast of Harney Lake	134 to 150	.4	20
224	....do	At east edge of Mud Lake	65		1
225	September 16	At west edge of lava from Diamond Craters			1±
226	July —	Buzzard Spring, in plateau southeast of Harney Lake.		[a].3	[a]15
227	November 1	5 miles north of the P ranch	78	4	200
228	August 27	4 miles northeast of the P ranch		1.4	70
229	....do	1 mile northeast of the P ranch	83		2
230	August 28	1 mile southwest of the P ranch	89	.4 or .6	20 or 30
231	August 30	At lake near summit of Steens Mountain		.1	5

CATLOW BASIN.

		STREAMS.			
111	September 3	Rock Creek, at Steve Young's		0.5	25
112	September 1	Home Creek, at mouth of canyon		3	150
113	September 6	Threemile Creek, at road crossing		4.5	225
114	October 30	Skull Creek, near road crossing		5	250
		SPRINGS.			
232	August 31	Roaring Springs, at Roaring Springs ranch; total flow of numerous springs.	59	5	250
233	September 3	On upper Rock Creek	105 to 115	.1 or .2	5 or 10
234		At Beattys Butte; five small springs		[b].1 or .2	5 or 10
235	September 6	Near HL ranch; ten small springs		.5	25

ALVORD BASIN.

		STREAMS.			
115	September 14	2 miles north of Juniper Lake		0.3	15
116	....do	4 miles south of Juniper Lake			3
117	....do	4 miles north of Mann Lake		.1	5
118	....do	1¼ miles north of F. Miranda's		.4	20
119	....do	At F. Miranda's		.6	30
120	September 13	1 mile west of the Alvord ranch		2	100
121	September 12	2 miles south of the Alvord ranch		.2	10
122	....do	4 miles south of the Alvord ranch			3
123	....do	2 miles north of Andrews		.3	15
124	....do	Wildhorse Creek, 2 miles north of Andrews		.3	15
125	September 9	Trout Creek, [c] at mouth of canyon		1.3	65
126	September 8	Mineral Creek, ¼ mile west of Denio		.1 or .2	5 or 10
		SPRINGS.			
236	September 14	Near divide on road between Juniper Lake and Mule ranch ("Summit Spring").			¼+
237	September 12	3 miles south of the Alvord ranch (boxed and used as domestic supply).	56		No flow.
238	....do	At west edge of Alvord Desert	168 to 177	.3	15
239	September 11	2½ miles southeast of Andrews (Mr. A. C. Bustamante, owner).	56	.5	25
240	September 7	¼ to ½ mile north of the borax works	[d]	[e]	[e]
241	....do	At borax works	82 to 97(?)	2	100
242	October 29	At roadside, near divide between Alvord and Catlow valleys.	55		2
243	October 27	On north side of Trout Creek, ½ mile below mouth of Little Trout Creek.	128	1	5

[a] From statement of F. M. Anderson, geologist.
[b] Reported.
[c] A measurement on June 15, 1907, near the Trout Creek ranch, is said to have shown a flow of 2,200 miner's inches.
[d] Near the boiling point.
[e] Not measurable.

Estimates of flow in the Harney basin region, Oregon, during the summer of 1907—Con.

WHITEHORSE BASIN.

Number.	Date, 1907.		Temperature.	Discharge.	
				Second-feet.	Miner's inches.
		STREAMS.	° F.		
127	September 10	Willow Creek, at road crossing		1.4	70
128	do	Whitehorse Creek, at road crossing		.2	10
		SPRINGS.			
244	do	5 miles northeast of Flagstaff Butte (seeping springs)			2 or 3
245	do	½ mile east of No. 244	96 to 100		3 or 4

MALHEUR RIVER DRAINAGE.

		STREAMS.			
129	August 5	Crane Creek, 2 miles below mouth of Gorman Creek		0.2	10
		SPRINGS.			
246	August 7	Warm Spring Valley, sec. 23, T. 22 S., R. 36 E	138 to 144	.2	10
247	August 6	Sec. 2, T. 25 S., R. 36 E. (Chris Dennean, owner)	58	4	200
248	do	¼ mile east of No. 247	58	.5	25
249	August 8	2½ miles southwest of No. 247 (seeping springs)	104 to 108	.2	10
250	August 6	Near mouth of Swamp Creek		.6 or .8	30 or 40
251	August 5	On north side of Crane Creek canyon			1+
252	do	On west edge of Crane Creek valley			1+
253	do	Sec. 10, T. 25 S., R. 34 E. (Developed)	55		1+

WARNER LAKE DRAINAGE.

254		Mule Spring (an old military well)		(a)	(a)

a No summer flow.

UNDERGROUND WATER.

DIVISIONS OF UNDERGROUND WATER.

Underground water may be considered in two broad divisions: Ground water, or that which exists in unconsolidated material, such as the alluvium of stream valleys, the sediments of lake basins, and the soil and rock waste of areas where the underlying rock has decayed in place; and rock water, or that which is present in the underlying rocks themselves. The zone of the former extends from the upper surface of saturation, the ground-water level, to bed rock, while the deeper water is present in the bed rock down to a depth below which, because of heat and pressure, meteoric water does not circulate. This lower limit has been theoretically placed at about 6 miles below the surface. In general, rock water is found at a much greater depth than is that of the surficial deposits, but in many places there is no definite line of division between the two classes, the unconsolidated surface deposits passing by easy gradations into the consolidated

rock below. It is therefore not always possible accurately to classify underground water, and the supply of many wells is as rightly considered to be from one source as from the other. In few places is the division between these two classes of water as sharply defined as it is in the Harney basin region by the surface of the lava flows. Within the lavas is the rock water, while in the valleys upon the lava bed rock lie the very different deposits of unconsolidated lake sediments and alluvium in which ground water is found.

GROUND WATER.

UNCONSOLIDATED MATERIAL.

The depth to which unconsolidated material may accumulate depends mainly upon climatic, structural, and topographic conditions. When streams bring down quantities of débris from mountain slopes and debouch upon valley lands, where the current becomes slower, the streams drop the greater part of their loads, and alluvial cones or fans are built up. Where streams empty into lakes, deltas are formed by similar deposition, while over the lake bottoms there are formed more even layers of material that was held longer in suspension by the inflowing water.

In many desert regions the wind, when it has been checked by mountain ranges or by contrary air currents, has deposited a deep loose layer composed of fine material picked up elsewhere. When laden with particles of sand and dust, it may also wear down exposed cliffs and peaks, and thus aid in forming the surface deposits of the lowlands.

In regions that are covered by residual soil the depth to which rock decay has taken place varies between wide limits. Over arid plateaus such soil may be only a few inches in depth, or in some parts entirely lacking, while in regions of great rainfall, especially within the tropics, rock decay may extend downward for several hundred feet.

GROUND-WATER LEVEL.

Where the loose material is of sufficient depth, seepage from stream channels and the direct supply by precipitation keep it saturated below a depth that is known as the ground-water level. This level varies with the supply of underground water, rising toward the surface as the supply increases and falling as it decreases. Its surface is closely related to the surface of the ground, to which it conforms in a general way, but it does not rise so high in the uplands and may not drop so far in the lowlands. Consequently along the sides of deep valleys and canyons the land surface in many places intersects the plane of the ground water, and springs result. These dry up

when the water level drops below the surface of the ground and increase their flow when it rises so as to produce greater head at the springs.

Within Harney County the ground-water level is at a shallow depth in all the lake valleys, and also in the smaller alluvial basins of the plateau regions. It is from this source that the shallow wells of the valley lands obtain their supply, while within the mountain portions many intermittent springs that issue along the canyon sides show where the ground-water level is intersected by the steep slopes.

ROCK WATER.

Relatively porous beds of rock, such as sandstone, underlie many regions and are the main sources of their water supply. Under the most favorable conditions these beds form the surface in other parts of the country, and directly absorb rain and melting snow; but in many places they are supplied with water chiefly by seepage downward through the overlying material.

The tuffaceous beds that are associated with the basalts of southern Oregon become excellent water carriers where their higher portions are exposed so as to collect rain and melting snow, and are an important source of the underground water supply. At Burns many of the wells pass through a surface layer of compact tuff to a more porous layer, in which a good supply of water is obtained. This is a rock water, since it is obtained from a bedded structural formation, although most of the wells are less than 100 feet deep, and the supply is probably from direct precipitation on the slopes to the northwest.

ARTESIAN CONDITIONS.

Since the time when the term "artesian" was first applied to flowing wells, from their notable occurrence near Artois, in France, the word has been used chiefly in reference to wells in which the water is under sufficient pressure to cause it to overflow at the surface. Within the past few years, however, there has been a looser use of the word, and it has sometimes been applied to any deep well, whether sunk for oil or water. Better usage, however, restricts it to those wells in which the water is under sufficient pressure to cause it to rise notably above the depth at which it is struck, whether or not it overflows at the surface. In this sense it will be used in the following discussion.

Since the publication in 1885 of the excellent paper by Chamberlin[a] the typical trough-shaped or saucer-shaped basin, or alluvial artesian slope, has often been considered essential to artesian conditions.

[a] Chamberlin, T. C., Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 125–173.

In a typical structural artesian area the underlying rocks are composed of alternate pervious and impervious beds, folded so as to form an inclosed basin. Water that penetrates to the pervious beds is confined within them by the impervious layers above and below, and the head produced on the water in the lower portions of these underground reservoirs by that in their upper parts, around the border of the basin, is sufficient to cause the water to rise in wells put down in the lowest parts of the basin.

Although the rocks of Harney County are of effusive origin, and so would not seem at first thought to furnish such conditions of bedding and structure as are demanded of artesian basins, yet the lava sheets interbedded with porous tuffs do give the alternation of pervious and impervious layers that produces artesian conditions. Four of the valleys of this region are to some extent synclinal or saucer-like in structure, and this feature will be treated in detail in considering the water possibilities in them.

In many places alluvium and sediments deposited in former lakes have filled valleys with alternating layers of coarse and fine material, that often act essentially as pervious and impervious beds in the production of artesian head on the underground water. The current of a stream that flows down from mountain slopes is checked on entering the lowlands or on discharging into a lake, hence it drops a great part of its load of sand and gravel and other alluvial material. This is largely assorted by the continued slowing of the current, and the coarser particles are dropped first, while the finer are held longer in suspension. In this manner layers of coarse and fine material are deposited that thin out down the slope into wedgelike sheets. The layers of fine material act as relatively impervious beds, confining water that seeps downward mainly to the coarser layers. These layers, by virtue of their slope toward the lowest portion of the alluvial cone, or of the lake basin, produce a head on the water thus confined that is in many localities sufficient to supply flowing wells when the water-bearing strata are properly tapped.

In certain parts of Harney and Alvord valleys conditions are favorable to the development of artesian water in the valley fillings, and flowing water has been developed in them to a slight extent. The successful wells and their locations are described in the detailed discussion of these valleys.

Although the most important areas where artesian water is found belong to one or the other of the typical classes, many artesian wells and even some flowing wells are obtained in regions that do not have the major structural features, but in which local factors, such as fissures and minor folds, produce artesian conditions in limited areas.

CONSERVATION OF THE WATER SUPPLY.

In concluding the general discussion of the surface and underground water supply of this region a few words may be said about the character of the drainage basins and the relation of forests and other protective growths on the mountain slopes to the flow of the streams.

In most of the streams of the area studied the discharge is at the maximum in the early spring, and is of short duration; and throughout the summer, when water is most needed, many of the streams are dry. In the absence of storage reservoirs the higher brushy and forested areas are the only places where the winter supply of water is conserved, by which the later stream flow is prolonged. The greater part of the drainage basins of Silvies River and of Silver Creek still have their natural protection of open forest, since lumbering has not yet become extensive in this remote section; but even on these streams the records that have been kept show how irregular the discharge is, and emphasize the desirability of preserving the naturally scanty covering of trees. In this respect it is gratifying to note the thick growth of young trees in many parts of the forested slopes on the northern side of the Harney basin. Farther south the slopes are protected mainly by brush and the lower growth of grasses. In Steens Mountain, the Whitehorse Mountains, and the Trout Creek Hills, the injury to this already scanty protection by the overgrazing of bands of sheep is becoming very apparent, as it is in many other parts of the Northwest, and it is to be regretted that these areas have not been incorporated into National Forests, if only for the purpose of limiting the number of sheep allowed to graze within them. It was reported that there were 128,000 sheep in the Whitehorse Mountains during 1907, and that some of the herders were cutting down the cottonwood trees so that the animals might browse on their leaves and twigs. The diminution in the flow of Trout Creek, caused by so many animals feeding along its upper course, was said to be very apparent.

The supply of underground water is also dependent for its constancy upon the accession to it throughout the year of water from the mountain slopes. In some parts of the United States, notably in southern California, the conservation of the winter rainfall in the high mountains and its continual seepage to the lower lands are of vital interest to those who pump water for irrigation. While it is probable that not for many years to come will the underground water supply in the valleys of Harney County be seriously affected by conditions on the surrounding slopes, yet the following two instances show that there is a very appreciable flow of the shallow subsurface water, and that its supply may easily be influenced by

storage conditions on the mountains. In summer, during the low stage of Silvies River, many seepage springs appear along its western bank, which seem to be best explained as due to eastward seepage of the underground water. At Harney it was reported that in one well near the bank of Rattlesnake Creek the water stands within 2 or 3 feet of the surface in summer, but in winter, when the ground freezes and stops the subsurface flow, it drops to about 15 feet.

DETAILS OF THE SEVERAL BASINS.

HARNEY BASIN.

LOCATION AND SURFACE CHARACTER.

The central part of Harney County is occupied by a wide, flat, alluvial area that is known as the Harney basin. This term is usually applied to the valley lands and is not here meant to include the entire drainage basin. The main part of this basin is occupied by the rudely square Harney Valley, which is 20 to 30 miles across. Portions of the valley that extend outward along stream courses, or are partially separated from the main area by hills, have local names, such as Happy Valley and Warm Spring Valley.

On the north, gentle slopes rise from the basin's edge to the Strawberry Mountains; on the northeast the steeper slopes of Crow Camp Hills border the valley land; while southward and westward it stretches to the base of Steens Mountain and to the high desert beyond Harney Lake and Iron Mountain. Within its borders a few isolated buttes rise, such as Saddle Butte, near Lawen; while projecting fingers, such as Wrights Point, extend into it and break the monotony of the wide level expanse.

LAKES.

In the southern portion of the Harney Valley lie Harney and Malheur lakes, two large water bodies that occupy the lowest part of the basin. These lakes were formerly separated by a sand spit about 4 miles northwest of Narrows, but it is said that in 1877, during a period of high water, this barrier was broken through, and Malheur Lake is now united with the western and slightly lower water surface by a strait 50 or 75 yards wide.

The water of Malheur Lake is comparatively fresh, while that of Harney Lake is strongly alkaline. This fact has been commented upon by Russell,[a] who cites it as an interesting example of the freshening of one lake by overflow into another. It would seem that the barrier, which separated the lakes prior to 1877 was only a tem-

[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903, p. 31.

porary one, since connection between the two lakes for a long period was probably required to render the eastern one now fresh and the other strongly alkaline. The following analysis of water from Harney Lake, collected August 5, 1902, is taken from Russell's paper.[a]

Analysis of the water of Harney Lake, Oregon.

[Parts per million. Analyst, George Steiger.]

Silica (SiO_2)	28.7
Aluminum (Al)	None.
Iron (Fe)	None.
Magnesium (Mg)	6.8
Calcium (Ca)	None.
Sodium (Na)	3,604.5
Potassium (K)	192.8
Carbon trioxide (CO_3)	2,974.7
Hydrogen (H) required in formation of bicarbonate	32.3
Surphuric anhydride (SO_4)	773.3
Chlorine (Cl)	2,771.3
Bromine (Br)	None.
Iodine (I)	None.
Boracic acid (B_4O_7)	92.8
Total	10,477.2

Specific gravity, 1.081.

NOTE.—Reaction strongly alkaline. The computation shows that no free carbonic acid is present above that required to form bicarbonates.

Of this analysis he says:

Judging from the analysis given above, the most abundant salts contained in the lake waters are sodium chloride or common salt, sodium carbonate or bicarbonate, and sodium sulphate. Potash and borax are present, but as the total amount of saline matter in solution is only 1.04 per cent by weight, the lake waters can not be considered as being of commercial value.

The seasonal variation in the water level of Malheur Lake and the consequent change in its area have already been mentioned. The record of gage readings that were taken at the wagon bridge at Narrows under direction of the U. S. Geological Survey shows that this change in level during 1903, 1904, and 1905 was in excess respectively of 4.3, 5.7, and 3.05 feet, the lake surface being highest in May and June and lowest in January and February. At low water the strait at the gage was dry, so that the total change in level was not recorded at this station.

SETTLEMENTS.

In 1907 there were four settlements in Harney Valley, at Burns, Harney, Lawen, and Narrows. These are connected with each other by good wagon roads and by telephone lines. Burns, the county

[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903, p. 31.

seat, is the center of trade for the valley, but at the smaller places, supplies and hotel and livery accommodations can be obtained. Within the past two years a great part of the valley land has been filed upon by new settlers, as homesteads and as desert claims, so that many small houses now dot it and the sagebrush is being cleared off. The land north and east of Dog Mountain, in the region known as Sunset Valley, was being settled most rapidly in the summer of 1907. In the area south of Harriman post-office, and also in the neighborhood of Windy Point, a number of settlers had taken up claims, while along the borders of the valley east of Harney there was another scattered group of new homes.

AGRICULTURE.

Ever since the natural resources of this region first made it a grazing country the valley lands as well as the plateaus have been devoted mainly to stock raising, and agricultural development has been limited chiefly to the increase of the natural hay lands by the construction of irrigation ditches and the use of the flood water. The belt of natural hay land along lower Silver Creek has been greatly widened by this means, and between Burns and Harney a large acreage that is irrigated by overflow water from Silvies River and from streams along the northern side of the valley produces crops of wild hay. But the natural grasses of these lowlands are mainly species of tules and flags, in which there is little nourishment, and unless an animal is in fair condition in the fall, even though it has access to the haystacks, it may not survive a severe winter.

Along the borders of Malheur Lake, in the vicinity of Narrows, the more alkaline soil yields a fair crop of salt-grass hay, which, though coarse, is more nutritious than the tule grasses of the overflow lands. In the upper portions of the meadow lands along the several streams there is considerable timothy, brome, and rye grass, so that the natural hay of these localities is better in quality than that farther downstream. Much of the lower marsh land is overgrown with tules and is covered with water during the greater part of the year. Of such character is the marsh or swamp land on the western border of Harney Lake, that along the sloughs in the neighborhood of Lawen, and portions of the lower course of Donner und Blitzen River and of the streams that enter it near the Buena Vista ranch. A few years ago an attempt was made to drain the portions known as the Buena Vista and Diamond swamps by dredging canals through their centers, but the yielding nature of the saturated peaty land soon allowed these channels to become choked up. Within the last two or three years ownership of these swamps has changed hands, and in the fall of 1907

a second attempt was being made to reclaim them, this time by dredging canals along their borders. A dipper dredge of 1¼ cubic yards capacity was in use, and a canal about 30 feet wide and 10 feet deep was being dug. Some attempt was made to use the peat that has formed in portions of the swamp as fuel for the dredger, but where it was cut it contained too much earthy matter to be valuable for that purpose.

Of late years grain, fruits, and vegetables in rapidly increasing quantities have been raised, and the influx of settlers has given great impetus to farming. At and near Burns there are several small farms that supply the greater part of the fruits and vegetables for local consumption, while east of the town several fields containing good stands of wheat and barley were noticed during the summer of 1907. A grist mill on the bank of Silvies River, a couple of miles north of Burns, furnishes much of the flour for local use; but many people still drive southward to Lakeview, or eastward to Ontario, for the winter's supply of apples and for potatoes and other vegetables, and as yet (1908) agriculture can be considered only as an auxiliary means of livelihood in this valley.

It is mainly the new settlers on the open sagebrush lands who have begun to raise much grain. Rye is a favorite first-year crop, perhaps on account of its suitability to dry farming, and where it has been sown under favorable conditions it has yielded well. Many of the new settlers expect to rely on dry farming, principally grain raising, for a living. They can not yet be assured of success, considering that their fields are in many cases limited to 160 or 320 acres, that the seasonal rainfall is uncertain, and that until a railroad is built through the region the market will be limited to the local demand.

AREAS TRIBUTARY TO HARNEY VALLEY.

In the valley of upper Silver Creek, at and above Riley, there are several ranches that have been occupied for a number of years, but here, as elsewhere, the bottom land is valued chiefly for its natural grass. On each side of the valley there are stretches of gravelly bench land which are at present used only as stock range, but they could be made productive if they were irrigated. Along the middle course of the stream, 6 or 8 miles south of Riley, a few homesteaders have settled, but little development of the land had been accomplished there at the time of this examination. There is a considerable area of good bottom land along this portion of the stream, and water is obtained at shallow depth, but no water is available from Silver Creek at the time when it is needed for irrigation.

Along Silvies River above Burns there are a few small farms, and also along Rattlesnake Creek, above Harney. At Diamond, on the southeast edge of Harney Valley, and in Happy Valley, along Smith and Riddle creeks, there are a few earlier settlers, but as in the other watered localities, which, of course, were settled first, the meadow grass, being a necessity to stock raising, is the most extensive and valuable crop.

Half a mile northeast of Diamond, Swamp Creek has cut through a lava ridge which resembles the ridges along Smith Creek, described on pages 27, 28. This forms a very good dam site for a reservoir of small capacity. The value of such a reservoir for irrigating the meadow of the lower portion of the creek is realized by the owner of the land, but at the time of visit a dam had not been begun.

SOIL.

CLASSES.

In Harney Valley, and also in the other valleys of this basin, six general classes of soil may be recognized by the character of the native vegetation. Nearly all the cultivable areas are covered by rather fine-grained, light, and sandy soil that is easily tilled, but it varies in alkalinity and in the amount of vegetable matter it contains. Near the lakes the percentage of alkaline salts is much greater than in the higher portions, while in the marshy and swampy areas the soil is black from decayed vegetation, and in certain localities, as in the Buena Vista swamp, it is even peaty in character.

The sagebrush land is in nearly all parts the best in quality, usually being light and sandy and free from alkali, while water of fair quality is often found beneath it at a shallow depth.

In the more alkaline areas sagebrush is replaced by greasewood, although the latter does not everywhere indicate especially alkaline conditions. Where it flourishes, however, ground water is usually nearer the surface and more alkaline than in the sagebrush areas.

Over some portions the rayless golden-rod, often called "rabbit brush," is the chief growth. Like the greasewood, it may indicate a dryer as well as a more alkaline condition of the soil.

Rye grass grows luxuriantly in land slightly above the marsh areas, which is overflowed during part of the year. In many places on hillsides it indicates the presence of seepage springs.

The marsh and natural hay lands may be considered as constituting a fifth class of soil, in which water stands close to the surface throughout the year. These lands are dark colored and rich in vegetable matter and are not, as a rule, badly alkaline, perhaps because of a continuous though slow movement of the subsurface water toward the sloughs that drain them.

In the lower lands, especially around the borders of the lakes, the alkaline content becomes excessive, and only salt grass and saltbushes grow.

No attempt can be made here to classify all the land of the Harney Valley, but it may be said that the best areas of sagebrush land were noticed along the borders of the valley between Harney and the Crow Camp Hills, in the neighborhood of Windy Point and Harriman post-office, and north and southwest of Dog Mountain. It is in these areas of sagebrush land that most of the recent settlement has taken place. There is also much similar land lying east and southeast of Burns, but 69,000 acres of this was still, in 1908, reserved by the State under the Carey Act, while 11,000 acres more is Indian land.

The western extension of the valley, in the neighborhood of Iron Mountain and Silver Lake, is an alkaline greasewood flat. A similar greasewood playa lies on the eastern edge of the valley near Malheur Gap, while a belt of rank greasewood borders the north shore of Harney Lake.

South of Malheur Lake the road that leads to Happy Valley crosses a belt of goldenrod land about 1½ miles wide. No homes had been built there, and though the soil is composed of alluvium and lake sediments it seemed hard and dry. South of this locality the surface rises gently to rocky plateau land.

Between Burns and Lawen several fields thickly covered with rye grass were seen; these are probably overflowed during the spring months by water from Silvies River. Other smaller rye-grass areas were noticed in the valley of Silver Creek and in the flat of Swamp Creek near Diamond.

The marsh and meadow lands include several fields east of Burns that are irrigated by means of ditches from Silvies River during high water, as well as the areas of natural marsh that are shown on the reconnaissance map (Pl. II). With the exception of those portions that are partially flooded and grown to tules, and the strongly alkaline areas that support only the saltbushes, these constitute the wild hay lands.

The greatest extent of alkaline salt-grass land noticed is along the western border of Malheur Lake. From parts of this, as has been said, the salt grass is cut for hay.

ALKALINITY.

Since the meaning of alkali is but slightly understood by many, it may be said here that several natural salts are known as "alkalies." The chloride, the sulphate, and the carbonate of soda are the three chief salts thus designated, the two former being "white" alkalies, while the latter is known as "black" alkali. Borax (biborate of soda) is also

an alkali, but only here and there is it present in sufficient quantity to affect vegetation. The nitrate and the phosphate of soda and the sulphate of potash are also alkaline salts that are found in nature, but these are nutritive salts and are essential to plant growth. The carbonate of soda or black alkali is the most harmful of these salts, as it attacks the bark of plant stalks just below the surface, and when sufficient in quantity practically girdles them.

Concerning the relative harmfulness of the three chief alkalies C. W. Dorsey says:[a]

> When present in soils to the exclusion of other salts, 0.05 per cent of sodium carbonate represents about the upper limit of concentration for common crops. One-half of 1 per cent of sodium chloride is commonly regarded as the endurance limit of crops, and 1 per cent of sodium sulphate. Sodium sulphate, then, is the least injurious and sodium carbonate the most injurious of the salts usually constituting the greater part of alkali under ordinary field conditions, while sodium chloride occupies a middle position.

Alkali is seldom distributed uniformly in the soil in a vertical direction. In most arid regions it is contained mainly in the upper 6 feet. Other factors besides the total quantity present in the soil modify its effect on plant life, especially the depth below the surface at which it is concentrated. This depth varies with the season and is greatly influenced by irrigation. Where the alkali is contained mainly 3 or 4 feet below the surface, shallow-rooted crops can be grown without injury; and in many places, also, it becomes concentrated in the surface crust, above the roots of plants that might otherwise be affected by it.

A few settlers have taken up claims on the borders of Malheur and Harney lakes. They were probably attracted to this section by the growth of salt grass and by the moist character of the land, but it is to be regretted that they were not informed of the worthlessness of such land for agriculture.

A soil sample was taken to a depth of 6 feet with an earth auger, half a mile south of Narrows, in the zone of greasewood land intermediate between the areas of sagebrush and of salt grass. The amount and character of alkaline salts in it were determined for each foot in depth separately, in order to learn their distribution as well as the quantity in the soil. A similar sample for analysis was taken in rye-grass land about 2 miles north of Lawen, in order to judge of the character of this class of soil. The results of these two analyses are as follows:

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[a] Dorsey, Clarence W., Reclamation of alkaline soils: U. S. Dept. Agr., Bureau of Soils, Bull. No 34, 1906, p. 10.

Alkali analyses of soils from Harney County, Oreg.

[Walton Van Winkle, analyst.]

PER CENT OF TOTAL SOIL (WATER EXTRACT).

Locality and depth of sample.	Soluble salts.	Ca.	Mg.	Na+K.	SO_4.	CO_3.	HCO_3.	Cl.
One-half mile south of Narrows:								
0 to 1 foot	0.566	0.0286	0.0074	0.144	0.0604	0.0048	0.0996	0.120
1 to 2 feet	1.049	.0028	.....	.2383	.0584	.029	.174	.550
2 to 3 feet	.734	.005	.....	.367	.096	.059	.062	.145
3 to 4 feet	.662	.003	.....	.300	.028	.111	.100	.120
4 to 5 feet	.938	.077	.003	.261	.067	.130	.024	.097
5 to 6 feet	.864	.....	.....	.282	.048	.080	.110	.084
Two miles north of Lawen:								
0 to 1 foot	.202	.015	.....	.055	.055	.....	.057	.010
1 to 2 feet	.126	.024	.005	.029	.011	.....	.040	.006
2 to 3 feet	.114	.030	.005	.027	.010	.....	.036	.006
3 to 4 feet	.140	.018	.006	.029	.010	.....	.041	.010
4 to 5 feet	.128	.017	.005	.034	.011	.....	.038	.008
5 to 6 feet	.194	.016	.....	.055	.017	.....	.057	.020

PER CENT OF SOLUBLE SALTS.

Locality and depth of sample.	Ca.	Mg.	Na+K.	SO_4.	CO_3.	HCO_3.	Cl.
One-half mile south of Narrows:							
0 to 1 foot	5.05	1.30	25.44	10.67	0.848	17.6	21.2
1 to 2 feet	.267	.....	16.8	4.14	2.05	12.3	52.4
2 to 3 feet	.694	.....	50.0	13.1	8.03	8.44	19.75
3 to 4 feet	.453	.....	45.3	4.23	16.7	15.1	18.1
4 to 5 feet	8.20	.319	27.8	7.14	13.8	2.53	10.3
5 to 6 feet	.....	.....	32.6	5.55	9.23	12.7	9.72
Two miles north of Lawen:							
0 to 1 foot	7.42	.....	27.2	27.2	.....	28.2	4.95
1 to 2 feet	19.0	3.97	23.0	8.73	.....	31.7	4.76
2 to 3 feet	26.3	4.38	23.6	8.77	.....	31.5	5.26
3 to 4 feet	12.8	4.28	20.7	7.14	.....	29.2	7.14
4 to 5 feet	13.2	3.90	26.6	8.59	.....	29.6	6.25
5 to 6 feet	8.24	.....	28.4	8.76	.....	29.3	10.3

The main point to be noted in the figures for the first sample is the high percentage of soluble salts and their persistence to a depth of at least 6 feet. Their proportion, from over one-half of 1 per cent to a little over 1 per cent of the total soil, shows that a harmful quantity of these salts is present; and as drainage conditions are poor the soil is almost worthless for crop production. The second sample, from near Lawen, contains only about one-fifth as much soluble material as the soil from near Narrows, and so far as alkalinity is concerned it may be classed as a good soil. Both are rather deficient in lime, as it is usually considered that for a good soil from 0.1 per cent to 0.3 per cent of this essential plant food should be present. Like nearly all other arid-region soils, however, that of this valley is fertile and will prove very productive where ample water can be supplied and alkali does not become excessive.

In one of his publications on this region[a] Russell gives the following analysis of a sample of the alkaline efflorescence from land near Dog Mountain. This also shows the nature of the salts that are present in this locality.

[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol Survey No. 217, 1903, p. 36.

Analysis of efflorescence from Narrows, Oreg.

[Analyst, George Steiger.]

Insoluble in hot water	1.25
Sodium oxide (Na_2O)	47.49
Water (H_2O) of crystallization	10.08
Sulphuric anhydride (SO_3)	11.76
Chlorine (Cl)	2.90
Carbon dioxide (CO_2), carbonic acid gas	26.33
Boracic acid (B_2O_3)	.28
	100.09

Regarding this analysis Russell says:

Judging from the above analysis, the efflorescence from which the sample examined was obtained, if in sufficient quantity and commercially accessible, would be of value for the sodium carbonate and sodium bicarbonate it contains, but not for its borax.

SURFACE WATER.

RECLAMATION PROJECTS.

A few years ago the United States Reclamation Service made preliminary surveys of two irrigation projects within the Harney basin. Of these, the Harney project embraced lands in the northern part of Harney Valley, while the other, the Silver Creek project, contemplated the irrigation of the bench lands along the stream above Riley.

Concerning the larger project, that in the Harney Valley, it is stated in the Third Annual Report of the Reclamation Service[a] that in 1904 there remained about 70,000 acres of unpatented land in the valley, and this had been selected by the State, under the Carey Act, for the Harney Valley Improvement Company. Measurements from May, 1903, to May, 1904, inclusive, showed that 250,000 acre-feet of water was discharged by Silvies River into the valley during that period. Much of the discharge is spring flood water, and it has been estimated that fully one-half the total amount can be stored at comparatively small expense at an excellent reservoir site at the head of Silvies Valley, about 20 miles north of Harney Valley. After making due allowance for the fact that the season of 1903–4 was one of unusual precipitation it was assumed that there is sufficient water to irrigate 40,000 acres, and that the necessary storage and distribution works can be constructed at a cost not to exceed $20 an acre for the land irrigated. But while the present method of irrigation by flooding is practiced, in which from two to five times the amount of water is used that would be necessary if it were properly distributed, it is doubtful if in seasons of average precipitation there is more water than is required to satisfy present claims. In June, 1904, a board of consulting engineers examined the project and recommended that it be abandoned, since the water supply would probably be found

[a] Whistler, John T., Operations in Oregon: Third Ann. Rept. U. S. Recl. Service, 1903–4, 1905, pp. 103–104 and 457–458.

insufficient during ordinary seasons. Throughout 1904 daily gage readings were made at a station on the river a short distance below the reservoir site, and showed a total discharge for the year of 163,400 acre-feet at this point. This station has not been continued, but occasional discharge measurements have been made on the stream, and they indicate, as was thought, that in some seasons the supply would be insufficient.

Concerning the Silver Creek project it is stated in the same report[a] that from preliminary measurements it was estimated that 100,000 acre-feet of water was discharged by Silver Creek during 1904. Since the flood water runs off early it was considered that fully 75 per cent of the total discharge could be stored without injury to the meadows below, and that storage would in fact be a benefit to much of the lower land. This estimate of discharge indicates that the amount available is sufficient to irrigate 40,000 acres, but to allow for a storage supply to tide over dry seasons about half this acreage was tentatively figured upon. The easily irrigable land is estimated at about 15,000 acres, only about 20 per cent of which is improved, and this only in the sense that it grows a light crop of wild hay; but about one-third of the land is patented through a military-road grant. There is a good reservoir site in the southwest corner of T. 21 S., R. 26 E., and in 1904 a preliminary survey of it and of the irrigable land below was made. Stream measurements made during the first half of 1905 and 1906 showed a much smaller discharge than in 1904, and the project has been practically abandoned by the Reclamation Service. In the summer of 1907 it was reported that a private company had purchased the ranch that occupies the reservoir site and intended to build a dam for storage purposes and irrigate part of the land below. The available discharge records of this stream are given on page 34.

MINOR IRRIGATION.

The main streams of Harney Valley, Donner und Blitzen and Silvies rivers and their tributaries, and the minor streams as well, have been described in the general discussion of the surface water (pp. 31–35), so they need not be taken up again here. Up to the present time their supply has been used only in irrigating and somewhat enlarging the natural meadow lands. In this irrigation it is the custom to turn the water upon these hay lands and to leave them flooded as long as the supply lasts or until the hay is ready to cut. In this way a great excess of water is applied to the crop, and in some portions the grass is often drowned out.

Of the several attempts that have been made in a small way at irrigation in Harney Valley, the following were noted in 1907: At the P ranch, at the south end of the marsh land of Donner und Blitzen

[a] Op. cit., pp. 459–460.

River, several fields of alfalfa have been irrigated, but for some years before this examination had been neglected. On Smith Creek and Rattlesnake Creek, as well as along Silvies River above Burns, a small amount of water is diverted from the streams to gardens and alfalfa patches. At Lawen one windmill was noted, which raises water from the slough and by means of a short flume irrigates a small vegetable garden. About 7 miles north of Lawen preparations were being made by one who had filed on a desert claim to raise water from the near-by slough by means of a centrifugal pump, and to conduct it through a wooden flume to the adjacent land. A mile or two west of Riley a dam had been built across the mouth of a natural depression at the valley edge, and the run-off water had been stored and used during the summer. In the spring of 1905 this dam broke, and up to the summer of 1907 had not been rebuilt. At the south base of Dog Mountain Mr. Newell has built across the mouth of a wide draw an earth dam about 1,200 feet long and 7 feet high at the center. This forms a storage reservoir with a capacity roughly estimated at 7 or 8 acre-feet. With the water thus stored he is able to give his wheat field a late spring flooding. A few similar small reservoirs were being constructed by other new settlers in this vicinity.

SPRINGS.

There are a number of springs, both natural and developed, within Harney Valley, which deserve mention in connection with the surface-water supply and its development. The following are the principal ones that were noted:

About a mile west of Burns, on the slopes 100 feet above the town, a spring rises, whose water is used to irrigate a few acres of garden and orchard immediately adjacent. An earth reservoir 300 feet long, 40 feet wide, and about 4 feet deep has been made by banking up around the spring, and a pit which was dug about 25 feet deep at the spring has considerably increased its original flow. This is estimated by Mr. M. L. Lewis, the owner, to be 1,000 or 1,200 gallons an hour, or about 2 miner's inches. Another spring 2 miles northwest of this one has been boxed in and forms a watering place at the roadside. Two or three similar springs rise in the hills southwest of Burns on the drainage slopes of Cold Spring Creek.

The warm springs 3 miles south of Burns and those near the mouth of Cold Spring Creek have been mentioned in an earlier part of this paper (p. 35) in speaking of the surface water supply. These flow in considerable volume, but no use is made of their water except in the irrigation of the natural meadow grasses.

At Mr. Newell's ranch at the south base of Dog Mountain the water supply for domestic and garden use and for several head of stock is obtained from a small developed spring in the coarse-textured tuff

that forms part of the mountain. A tunnel 80 feet long has been run into the hillside and yields a constant flow of somewhat less than a miner's inch.

The Weaver spring, 3 miles west of Mr. Newell's, at the edge of the valley, is also in part a developed one. The water issues from the base of a low scarp and supplies a small field of alfalfa, besides the usual garden. The flow is possibly 2 miner's inches.

A couple of miles north of Harriman post-office there is a hot spring, which in the summer of 1907 had been banked up so as to form a pool 100 yards in diameter. The water discharged on the east and south sides through two ditches having a total flow of about 28 miner's inches.

In Crane Creek Gap there is a small spring, which rises on the slope well above the level of this divide. At the time it was visited it formed a pool that was used by cattle as a watering place, but there was little appreciable flow. Farther down the slope there is a second spring and pool. A well-marked watercourse leading from it indicates that these springs flow in considerable volume during the earlier part of the year, and that their supply is mainly of shallow origin.

In the west end of Warm Spring Valley the spring numbered 212 on Plate III has little appreciable flow, but it has formed a small tule area and is a welcome watering place. Of similar origin are springs Nos. 211 and 213, but the former flows into Silver Lake and the latter into a small pond.

With the springs of the southern side of the Harney basin those of Buzzard Canyon may be mentioned. During the summer the water alternately rises to the surface and flows underground along this drainage course. The flow at Buzzard Spring is said by F. M. Anderson, geologist, to have been about 15 miner's inches in July, 1907.

Of the largest springs of Warm Spring Valley, those on the Double O ranch, it has already been stated that the water is used only to a small extent in irrigating the wild-hay land, though canals have recently been dug and preparations have been made for using it more extensively for this purpose.

The water of spring No. 221, southeast of the Double O ranch, is used mainly for garden irrigation, as is also that of spring No. 222, a mile farther east.

A hot spring, No. 223, rises near the southeast shore of Harney Lake through a number of vents in which the water ranges in temperature from 134° to 150° F. At this place a pool 115 yards long and from 10 to 35 yards wide has been formed, which discharges through two ditches at its southern end. The total flow as measured was about 20 miner's inches.[a] A few years ago some attempt was

[a] In Water-Supply Paper U. S. Geol. Survey No. 78, 1903, p. 39, Russell gives the flow of this spring as 6 gallons a second, equivalent to about 40 miner's inches.

made to utilize the water for irrigation on the land near by, but of late it is unused and sinks within 300 yards of its source.

About half way between this spring and Narrows there is a small sulphur spring in the barren flat close to the lake margin. Some one has built a cabin here, fenced in the spring, and attempted to raise a few potatoes, but with poor success.

The Sodhouse spring, No. 214, has been described on page 35. No attempt is made to utilize its water, but it forms a welcome drinking place for cattle, especially in winter, when its warm water is greatly appreciated by the animals.

A small spring by the roadside, at the western edge of the lava surrounding Diamond Craters, is worthy of mention, for though its flow is inappreciable it forms a convenient watering place for the traveler.

Numerous cold springs issue along the canyon sides of the creeks that drain the northern slope of Steens Mountain, and considerably increase the stream flows. In two or three places their water is used during the dipping and shearing of sheep, but because of their locations they are put to little other use directly.

GROUND WATER.

The ground-water level has been said to be at a shallow depth in nearly all parts of the basin. Near its borders the shallow ground water is much better in quality than it is near Lawen and Narrows. The level, where it is indicated by the depth to water in a number of wells, is shown on Plate III. Other notes concerning these wells are tabulated in the following list of those that were noted in the Harney basin.

Wells in the Harney basin.

No.	Owner or location.	Class of well.	Method of lift.	Depth to water.	Remarks.
				Feet.	
1	West side of Silvies River canyon.	Dug	Wheel and bucket.	25	Temperature 47° F.; unusually cold.
2	Harney	Bored and dug.		10 to 15	General statement for wells at Harney.
3	Northeast edge of Harney Valley.	Bored	Pitcher pump	5	
4	1 mile east of No. 3	Dug	Wheel and bucket	7	
5	1½ miles east of No. 4	do	do	7	
6	East side of Harney Valley	do	do	20	
7	2½ miles south of No. 6	do	do	9	
8	Fred Haines, sec. 2, T. 23 S., R. 32½ E.	Drilled	Windmill	15	See Russell's statement, quoted on p. 62.
9	7 miles southeast of Harney	Bored	do	10	
10	J. H. Shepard, 12 miles east of Burns.	Dug	Wheel and bucket.	8	
11	Mr. Dennison, sec. 18, T. 23 S., R. 32 E.	do	Windmill	15	
12	Harney County, sec. 13, T. 23 S., R. 31 E.	Drilled	Not used	5	See Russell's statement, quoted on p. 62.
13	Northern part of Burns	Mostly drilled.	Windmills and engine.	75	General statement for wells in upper part of Burns.
14	Southern part of Burns	Bored and dug.	Windmills	30 to 50	General statement for wells in lower part of Burns.
15	Mr. Geer, 2 miles west of Burns.	Dug	do	26	

Wells in the Harney basin—Continued.

No.	Owner or location.	Class of well.	Method of lift.	Depth to water.	Remarks.
				Feet.	
16	I. S. Geer, ½ mile south of No. 15.	Dug	Windmills	7	
17	Cal. Geer, near No. 16	do	do	10	
18	NW. ¼ sec. 33, T. 23 S., R. 29 E.	do	Wheel and bucket	60	Small supply; in tuff.
19	J. F. Oakerman, Riley	do	Windmill	14	
20	7 miles above Riley	do	Wheel and bucket	10	
21	7 miles south of Riley	do	Pitcher pump	10	
22	J. W. Sevedge, 9 miles south of Burns.	Bored	do	8	
23	Dan Harkey, 8 miles south of Burns.	do	Not used	7+	Pit dug 7 feet deep, nearly to water level, and cased boring sunk to a depth not learned. Water in casing stood 2½ feet below surface of ground.
24	N. B. Sutton, 1 mile east of No. 22.	do	Pitcher pump	15	Water level at 15 feet, but better quality of water at 71 feet.
25	1 mile north of Lawen	do	do	28	
26	½ mile northeast of Lawen	do	do	26	
27	Stable yard, Lawen	do	Windmill	12	
28	Hotel, Lawen	do	do	8	
29	G. L. Sitz, Lawen	Drilled			See log of well, and remarks, p. 62.
30	Sec. 7, T. 24 S., R. 33 E. (Burke well).	do	Artesian flow	6	See description, p. 61.
31	North side of Crane Creek Gap.	Dug	Not used	14	
32	Center of Crane Creek Gap	do	do	6	
33	Post-office, Harriman	Bored	Pitcher pump	25	Said to be bored to depth of 148 feet. Black ooze and stagnant water at 70 feet.
34	In flat east of Dog Mountain.	do	do	7 to 10	General statement for wells in this locality. Several water-bearing strata; better water usually in the deeper ones.
35	T. B. Beck, east base of Dog Mountain.	Dug	Wheel and bucket	30	
36	T. B. Beck, ¼ mile east of No. 35.	do	do	18	
37	I. S. Tyler, east base of Dog Mountain.	do	Pitcher pump	28	
38	Mr. Porter, east base of Dog Mountain.	do	Not used	40	Small supply, poor water.
39	A. Barron, 3 miles north of Dog Mountain.	Bored	do	63	Water struck at 63 feet; rose at first to 38 feet; in tuff.
40	Mr. Saddlemire, ¾ mile north of No. 39.	Dug	Pitcher pump	28	
41	½ mile west of No. 39	Bored	Not used	37	
42	1 mile northwest of No. 39	do	Pitcher pump	13	
43	Mr. Carpenter, 1½ miles northwest of No. 39.	do	do	28	
44	5 miles west of Dog Mountain.	Dug	Windmill	30	
45	10 miles north of Double O ranch.	Bored	Pitcher pump	24	Water also at shallower depths in this section; also better quality at greater depths.
46	1½ miles southwest of Narrows.	do	Not used	11	Water struck at 11 feet; said to have risen to 4 feet below surface.
47	1 mile south of Narrows	do	Windmill	12	
48	Narrows	do	Hand pumps and windmills.	10 to 15	General statement for wells at Narrows.
49	Mr. Springer, 6 miles east of Narrows.	do	Pitcher pump	12	Water said to come from same red tuff from which the Sodhouse springs issue; when first bored, water rose to within 1 foot of the surface.
50	do	do	Windmill	6	
51	County well, Windy Point	Dug	Bucket and rope	16	
52	Mr. Smith, sec. 6, T. 26 S., R. 34 E.	Drilled			See p. 60.
53	O. E. Thompson, sec. 18, T. 26 S., R 34 E.	Dug	Windmill	35	
54	¾ mile south of No. 53	do	Bucket and rope	24	

Aside from that supplied to gardens by a few windmills, little attempt has been made to use the shallow ground water for other than domestic purposes.

South of Narrows, in the lowland bordering Mud Lake, water under pressure is found a few feet below the surface, and also in a few places along lower Silvies River.

During the fall of 1907 a well was drilled on the east side of the valley, near Windy Point, in sec. 6, T. 26 S., R. 34 E. At a depth of 260 feet water was struck that rose to the surface, but a satisfactory flow was not obtained.

These evidences of pressure in the water of the valley filling make it probable that in some restricted localities flowing wells in the valley deposits will be obtained when the wells are properly sunk and cased. Although these may be obtained only in the lower portions of the valley, they may prove of use for irrigation on a small scale. Since the valley filling is comparatively shallow and the surface is very gently sloping, it is not probable that water exists in the unconsolidated sediments under sufficient head to yield flowing wells of great supply.

The depth of the valley filling could be judged only from the incomplete records of five wells that previous to 1908 had been drilled in it to the underlying rock. From the notes at hand concerning these it appears that in the county well, No. 12, rock was encountered at about 100 feet, and at about this depth also in Mr. Fred Haines's well, No. 8. A sample of the material from a depth of 280 feet in the Smith well, No. 52, indicates that at this depth the bottom of the valley sediments had been passed and that drilling was in a tuffaceous layer associated with the basalts. From the record of the well drilled at Lawen by Mr. Sitz, which is given on page 62, it appears that the valley filling is only 200 feet deep at this place, the remainder of the depth penetrated being through basalt and tuffaceous beds. In the Burke well, No. 30, drilling was stopped when resistant material, probably bed rock, was reached at a depth of 235 feet. Besides the records of these few drilled wells within the valley, the buttes that rise above its floor and the gentle dip of the rocks surrounding it also indicate that the unconsolidated filling is of comparatively slight depth.

The flatness of the valley surface is shown by the elevation of bench marks established by the United States Geological Survey along its margin and at the edge of the lake at Narrows. These elevations given indicate a slope of only about 50 feet from the northern margin of the valley to the lake, or only 2 feet to the mile over a great part of its surface. To the east, Malheur Gap is said to be only about 16 feet above the high-water level of Malheur Lake.

Although it is unlikely that strong flowing wells will be obtained in this valley in the alluvium and lake sediments, it is probable that the deeper water-bearing beds of unconsolidated material will later prove valuable sources of water for pumping. But the development of this underground supply will depend mainly upon the cost of pumping and the values that can be obtained from produce raised by irrigation; and until an easy outlet is obtained to a more extensive market than the local one it is not likely that extensive pumping will be found profitable.

The supply obtained at ground-water level has proved ample for domestic use, but it is not thought that this shallowest water will prove sufficient for extensive irrigation. On this matter the notes kindly furnished by Mr. W. E. Burke on his well (No. 30) northeast of Lawen are very instructive. At first a pit 6 feet square and 22 feet deep was dug, water being struck at 6 feet. It was the intention to pump from this shallow ground-water supply, but it was found that the pit yielded little greater supply than a 2-inch well. A 9-inch hole was then drilled, and at a depth between 90 and 100 feet a layer of sand was encountered, which yielded water that rose to within 7 feet of the surface. This layer was tested by pumping for two or three hours a day for several days, and when yielding 600 gallons a minute the level lowered to 32 feet below the surface; while when pumping 1,000 gallons a minute it lowered to 38 feet. At the bottom of the well another water-bearing bed was encountered, which yielded a surface flow of about 10 gallons a minute. In the summer of 1907 this well was still flowing sufficiently to form a pool 30 to 40 yards across, which had become a regular watering place for the range stock.

ROCK WATER.

STRUCTURAL CONDITIONS.

Around the borders of the Harney basin the bedded lavas slope toward it from all sides, as shown by the dip symbols on the geologic map (Pl. III), so that as a whole it is structurally a great saucer-shaped basin or syncline. Within this basin there are minor irregularities, of which Saddle Butte and other similar buttes are surface evidences, and probably there are other minor structural features of which there are no surface indications. In general, however, these are not considered to be sufficient to seriously affect artesian conditions within the basin.

DRILLED WELLS.

Of the five deep wells that have been mentioned, three were sunk into the bed-rock layers in an effort to obtain flowing water. The

first important drilled well was put down in 1893 at the expense of Harney County. Of it Russell says:[a]

A well drilled at the expense of Harney County in 1893, at a locality about 6 miles east of Burns, in sec. 13, T. 23 S., R. 31 E., was continued to a depth of 848 feet. The well at the top has a diameter of 6 inches, but narrows near the bottom to 4 inches. At a depth of 350 feet water was reached which rose and overflowed at the surface, but after an attempt to improve the well, made in the spring of 1902, it ceased to flow. The water in August, 1902, stood 3 feet below the surface and had a temperature of 49° F. The first 100 feet of material passed through was sand, gravel, and soft rock, and at a greater depth hard rock was penetrated, but no record as to its nature, etc., is available. Two water-bearing strata are said to have been reached, one at 350 feet from the top and the other at the horizon where drilling was discontinued, namely, 840 feet. The outflow from the first water-bearing layer is said to have been small. The well is cased with iron tubing, 6 inches in diameter, to a depth, as reported, of 450 feet.

During the summer of 1907 the water in this well stood about 5 feet below the surface, little, if any, above the ground-water level.

Russell mentioned the well belonging to Mr. Fred Haines,[b] of which he says:

About 5 miles east of Harney, on land belonging to Fred Haines, sec. 2, T. 23 S., R. 32½ E., a well 3 inches in diameter, drilled in 1896 to a depth of 507 feet, struck water at a depth between 200 and 300 feet, which rose to the surface. The well is not cased, and the water now stands 6 feet below the surface and has a temperature of 49° F. The material passed through was soft to a depth of 100 feet, and below that depth consisted of black lava, clay, etc., but no definite record is available. This well at first yielded a true artesian flow, but, as nearly as can be judged, has caved in, owing to lack of casing, and the water supply at present is from percolation through porous beds near the surface.

In a later paper[c] he gives the following record of a third drilled well, belonging to Mr. G. L. Sitz, which was put down at Lawen:

Record of Sitz well, Lawen.

	Feet.
Sand and clay	200
Lava, about	50
Gravel, cemented	4
Hard and soft layers, from 8 inches to 4 feet thick	100
"Hard blue granite" (basalt)	78
	432

He refers to this as a flowing well, but more recent information states that it did not flow.

The evidence furnished by the drilled wells indicates that porous beds of tuffaceous material, similar to those exposed at numerous places along the borders of the basin, exist beneath the valley and

[a] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Supply Paper U. S. Geol. Survey No. 78, 1903, pp. 40–41.

[b] Op. cit., p. 40.

[c] Russell, I. C., Preliminary report on the geology and water resources of central Oregon: Bull. U. S. Geol. Survey No. 252, 1905, p. 42.

are interbedded with rocks of firmer texture. These tuffs associated with the lavas do not form so uniform and persistent beds as do marine sandstones; they seem rather to form great irregular lens-shaped masses. These, however, are of sufficient extent to act as collecting reservoirs for percolating water, and by leakage from one bed to another some of them may serve the purpose of a continuous permeable stratum. An attempt is made to illustrate the relation of these tuffs to the basalt in the geologic cross section on Plate III, in which the thicker lines in the bedding planes represent lenses of tuffaceous material.

Of the three drilled wells that had been sunk in this valley to bed rock previous to the spring of 1908, the one that was put down at the expense of the county is considered to have been the best test for artesian water, for it is situated some distance out in the valley, was cased to solid rock, was sunk to a depth sufficient to be determinative, and did yield an artesian flow. The well of Mr. Fred Haines is nearer the valley edge and is of less depth, but the fact that it yielded a slight flow is favorable to the belief that valuable flowing wells can be obtained by deep drilling and proper casing. It is probable that had drilling been carried to a greater depth in the well of Mr. Sitz, at Lawen, a good flow of water would have been obtained, for beneath this central part of the valley conditions are thought to be especially favorable to the collection of water under pressure.

WARM SPRINGS.

Besides that furnished by the drilled wells in Harney Valley, other evidence of artesian conditions is given by the several warm springs that rise within it, especially by those about 3 miles south of Burns, and those of Warm Springs Valley, west of Harney Lake. In those places where the immediate source of the spring was seen, the water issues from coarse tuffaceous material that is interbedded with the lava. Its temperature is noticeably higher than that of the shallow ground water, and the flow is more constant and of greater volume than can well be accounted for by local surface supply. In all respects these springs resemble those that are found in other valleys in which flowing artesian water is obtained. The largest of these springs, near the Double O ranch, are locally considered to be supplied by water from the Cascade Range. Aside from the difficulties involved in distance and in the structures that intervene in the way of water that may travel eastward from these mountains, the position of the slopes of Steens Mountain as a collecting area, and probably also the plateau region south of Warm Springs Valley, favor a nearer source of supply. The fact that their flow has a seasonal variation, and is said to be one-third more in August and September than in April, also favors a more local source for their supply.

Of the spring 2 miles north of Harriman post-office, Russell,[a] writing in 1904, says:

About 4 miles northeast of Saddle Mountain Butte is a spring which, as observed by H. C. Dewey, forms an irregular pool from 75 to 120 feet in diameter and 20 to 30 feet deep. The water is clear, without odor, and near the margin of the pool has a temperature of 122° F. The discharge, which is about 430 cubic inches per second, is now utilized for watering stock. This spring rises at a locality on the broad surface of the valley, at least 4 miles from the nearest upland, and is a true fissure spring, having a deep source, shown by its temperature to be probably not less than 3,500 feet below the surface. Like other hot springs in the valley some account of which has been published,[b] it indicates the presence of artesian conditions.

In August, 1907, the discharge of this spring was about 20 miner's inches. The highest temperature that was recorded was 95° F., where the water rises near the center of the pool. This discordance in the measurements of 1903 and 1907 seems to corroborate the local statement that the spring is of variable flow and temperature. Concerning the origin of this spring it has been suggested by Dr. W. L. Marsden, of Burns, that faulting in the hills to the east, which has been discussed by Russell, may continue westward into the valley, and that this spring rises along a fault plane. Possibly the displacement continues across Harney Valley and up the valley of Sagehen Creek, and also furnishes a means of escape for the water of the springs along the lower course of this stream.

If such is the case, this faulting may render it impossible to obtain flowing wells near the fault line, but it is not considered that it seriously affects artesian conditions in the northern part of Harney Valley, nor in the cultivable area of its southern portion.

CATLOW BASIN.

DESCRIPTION.

Beyond the rocky table-land south of Harney Lake, and lying between Steens and Warner mountains, there is a long, shallow, relatively narrow basin. Its south-central portion, near the mouth of Skull Creek, is known as Catlow Valley, but as all the arable land of the basin is in one great body, the name Catlow Valley will here be applied to it as a whole. The valley is about 40 miles long, trends a little west of north, and has a fairly uniform width of 6 or 8 miles. On the northwest the rise to the higher land is gradual, but on the south and southwest low escarpments and steeper slopes mark the valley edge more clearly. On the east it is bordered by an escarpment that in its central portion reaches a height of 1,400 or 1,500 feet. The

[a] Russell, I. C., Preliminary report on the geology and water resources of central Oregon: Bull. U. S. Geol. Survey No. 252, 1905, p. 41.

[b] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Supply Paper U. S. Geol. Survey No. 78, 1903.

northern end of the valley is also marked by a bold escarpment that is superimposed upon the plateau to which one ascends from the lowland of the P ranch; for Catlow Valley lies 400 feet higher than the marsh of Donner und Blitzen River. Northward this branch scarp unites with the one bordering the marsh land of the river.

Terraces along its eastern border show that Catlow Valley was once occupied by a lake that extended northward nearly to the edge of the plateau overlooking the P ranch, but apparently it never became quite high enough to overflow through the pass at this point to the lowland of Donner und Blitzen River.

Most of the northern part of the valley is level and sagebrush covered, and only along its borders is it trenched by a few arroyos or flood-water channels. South of Skull Creek, in what was probably the deepest part of the former lake, a considerable part of the valley is covered with sand dunes and alkaline areas.

SETTLEMENT.

Catlow Valley was practically unsettled in the summer of 1907. The houses on the several cattle ranches are usually occupied only while the wild hay is being cut and stacked, but during the fall of 1907 a family remained at Home Creek ranch to care for fences and watering places on the range. One homesteader, Mr. Pearl Wise, had filed on a claim near the sink of Skull Creek. During the summer of 1907 he built a ditch to take a portion of the spring flood of this stream and impound it in an earthen reservoir for later irrigation. The lack of settlers in the valley seemed due mainly to the facts that nearly all of the surface water supply is controlled by the cattle ranches and that nearly all the newcomers have taken up claims in the less remote Harney Valley; for Catlow Valley lies away from the main line of travel, so that it is comparatively little known except to the cattlemen.

SURFACE WATER.

The five cattle ranches in this valley use the surface water to a small extent in irrigating the wild-hay land, but hold the several streams and springs chiefly as watering places for stock. Home, Threemile, and Skull creeks rise in the southern portion of Steins Mountain and debouch upon Catlow Valley along its eastern edge. In their middle courses these streams have steep grades, and have cut deep gorges where they descend from the plateau to the valley land. Where they enter the valley they have built extensive alluvial fans. Rock Creek, on the western side of the valley, gets its most constant supply from Warner Mountain, but during the run-off period it also receives the drainage from most of the surrounding

plateau country. In the spring most of its water does not flow beyond its sink in the northwestern part of Catlow Valley, while during the summer the stream is dry throughout most of its course. Along its middle portion, west of the Rock Creek ranch, there is an extensive strip of alluvial land, but the discharge of the creek is so floodlike and of such short duration that it could not be depended upon in this portion for irrigation purposes.

Walls Lake, a collecting place for the spring run-off from the neighboring region, lies in the unsurveyed country north of Catlow Valley, and its location as given on the reconnaissance map (Pl. II) is only approximately correct. It is said to be about 1⅛ miles long, ⅜ mile wide, and to average 4 feet in depth during most of the year. The utilization of its water on a body of arable land near it has been considered, but would involve digging a canal half a mile long and 20 feet deep in the maximum, at a cost roughly estimated at $5,000. It is reported that the lake has gone dry in years of slight rainfall, so an irrigation project dependent upon it for water would be likely to prove an expensive venture.

From the bluffs on the eastern side of the valley a number of springs come forth, of which by far the largest are those at the Roaring Springs ranch. The water here issues along the lower portion of the bluffs as two or three large and numerous smaller springs, and flows some distance out on the valley before it sinks. Except for the small area of natural hay land that the water irrigates, no use is made of it, though the amount, which is estimated at about 250 miner's inches, is sufficient to irrigate 800 or 1,000 acres. A similar spring augments the flow of Threemile Creek, while farther southward, near the HL ranch, nearly a dozen springs issue along the bluffs, from the same horizon, and water a small field of wild hay. On the lower slopes of Beattys Butte there are four or five small springs, which are kept cleaned out and form watering places for the range stock. On the upper course of Rock Creek there is a group of hot springs that yield a total flow of 8 or 10 miner's inches, from 105° to 115° F. in temperature. Advantage is taken of the temperature of this water in preparing sheep dip, a use to which a number of hot springs in southeastern Oregon are put.

GROUND WATER.

As very few wells have been sunk in this valley, the ground water conditions can be stated only in a general way, but it is thought that in nearly all parts of the valley water can be obtained within 30 or 40 feet of the surface, and in the lowest areas at much less depths. The wells in which the depth to water was noticed, which are all shallow dug ones, are indicated on Plate III. The well near the sink of Skull Creek, No. 58, which was put down in the summer of 1907, failed to

reach water in the sand and gravel at a depth of 40 feet. This well was dug on higher land, in the alluvium brought down by Skull Creek, in which the water probably sinks to a greater depth than elsewhere, but water can almost certainly be obtained here by sinking deeper in the alluvial material. At the Rock Creek ranch there are two wells (Nos. 56 and 57) close to the channel of the stream, in which the water stood respectively at 12 and 19 feet below the surface in September, 1907. North of the valley proper, and about 12 miles west of Walls Lake, the only settler, Mr. Chino, obtains water at about 15 feet in the alluvial land (well No. 55), and by the aid of a windmill is able to irrigate a small acreage.

Between Roaring Springs and the sink of Rock Creek there are two or three shallow ponds. These can hardly be supplied wholly by surface precipitation, and no evidence was seen that they are supplied by springs. Since they lie in slight depressions it seems probable that they represent the ground-water level at this point. If so, water must stand at less than 10 feet from the surface beneath much of the northern part of the valley.

Large alluvial fans have been formed where Home and Threemile creeks debouch upon the valley, and less perfectly where Skull Creek enters the open land. A number of springs as well as the streams themselves flow down and spread over these alluvial deposits, while other water may also enter the sands and gravels by seepage from the bluffs against which these deposits lie; hence it seems probable that small flowing wells similar to those of Alvord Valley, which are described later (pp. 74–77), can be obtained in the valley near the margins of these deposits, for these springs and streams keep the alluvium saturated with water, probably under sufficient head to produce flowing wells around the edges of the fans. A spring at the Home Creek ranch house, which furnishes the domestic supply, is probably of alluvial artesian water that escapes to the surface at this point, along the edge of the fan of Home Creek.

Judging from the slight inclination of the rocks on each side of this valley its unconsolidated filling is perhaps not over 200 feet in depth, and over its greater portion the surface is so nearly level that little head can be developed in the alluvial water; hence, except in the zone just outlined, in the lowlands about the margins of the fans, there is not much probability that artesian flows will be developed by wells sunk into the valley filling only.

GEOLOGIC STRUCTURE.

Since the surface of this region is approximately the original surface of the lava flows, the slopes are in general dip slopes. Along the western side of Catlow Valley the basalts dip eastward at a uniform low angle, and pass beneath the lake deposits. On its eastern border

the rocks that form the escarpment along that side of the valley dip gently to the west or northwest. Southward the slopes rise to a more mountainous country, while on the north low scarps in the plateau region also exhibit gentle west and northwest dips.

At first thought, the escarpment along the east side of this valley and the gentle slope toward it of the rocky desert to the west, suggest that the scarp has been produced by faulting, and that the country to the west is the surface of a tilted block. Lake Abert and northern Warner Lake, which are west of Catlow Valley, lie in basins at the lower sides of such blocks, and it is possible that Catlow Valley also lies upon the edge of such a tilted block. However, the following conditions lead to the tentative statement that the scarp bounding the eastern side of this valley has been produced, or at least made steeper and heightened, by progressive weathering action, and that the rocks underlying the valley form a great low syncline.

The escarpment along the middle portion of Donner und Blitzen River divides west of the P ranch. The western branch swings southwest along the border of the Catlow Valley and gradually dies out in the plateau region. The great escarpment along the east side of this valley is formed by slopes that gradually rise southward and culminate in the crest of Steens Mountain. Near Threemile Creek this scarp turns farther to the southeast, is superimposed, as it were, upon the slopes drained by Skull Creek, and unites with the Steens Mountain scarp at Whisky Hill. The remarkable steepness and regularity of this escarpment, and the sharp notches that have been cut in it by Home and Threemile creeks, suggest a fault origin, but no hot springs or other evidences of faulting were seen along any part of it. The springs that issue along it come forth well up on the face of the scarp, not from the edge of the valley alluvium as they would if they rose along fault fissures. One or two blocks were noticed that dip steeply toward Catlow Valley, but these are more probably landslide blocks caused by erosional agencies than blocks due to faulting. In respect to this scarp as a fault feature the statement made in the earlier discussion of structure may be repeated here—that in the case of the recognized fault scarps the rocks forming the uptilted blocks dip away from the bluffs, while those forming the scarp on the eastern side of Catlow Valley dip toward it.

It is difficult to determine closely the direction of dip of the lava beds of the Catlow basin, for they slope at angles of only 2° or 3° from the horizontal, and in few places is there a distinctive layer of lava or tuff that can be used for such a determination. It seems, however, that the surface rocks of the plateaus to the west, north, and east of Catlow Valley are all at least of the same horizon or period of effusion, if not of the same individual effusion or flow of lava. A dip of 3° westward would carry the upper beds of the scarp at Home Creek

beneath the valley 4 or 5 miles out from the scarp, so they may be continuous with those of the slopes on the opposite side of the valley. Or it may be that the beds composing the Catlow Valley scarp overlie those of the scarp along the eastern edge of Warner Valley and of the plateau surrounding Beattys Butte, but never extended so far westward, as is indicated in the generalized cross section on Plate III; and that the Catlow Valley scarp has been made more prominent by progressive eastward subaerial erosion. In the cross section the bedding planes represent series of effusions rather than separate flows, for it is not considered that each relatively thin sheet of lava is as extensive as is usually each bed of a sedimentary deposit.[a] If either of the above explanations of the structure is correct, Catlow Valley lies in the trough of a great shallow syncline.

Progressive erosion may also account for the 400-foot cliff at the northeast end of the valley. There is a small difference between the inclination of the beds composing this escarpment and that of the slopes south of it, which appears to carry the rocks of the latter beneath those of the higher plateau. The beds on each side of the cliff dip in the same direction, northwestward, but there is no evidence of faulting or of tilted block structure along the scarp.

ROCK WATER.

If the Catlow Valley scarp is a fault scarp it of course seriously affects rock-water conditions, if it does not render impossible the existence of artesian water beneath the valley. This is not considered to be the case, however, and the explanation of the structure as being synclinal is believed to be the correct one.

Aside from the structure, the numerous springs that issue along the east side of the valley furnish the best evidence in favor of the presence of artesian water. At Roaring Springs, at Threemile Creek, and near the HL ranch numerous springs issue from a coarse tuffaceous bed that seems to be continuous throughout the length of the scarp. The water of these springs is several degrees above the normal ground-water temperature, and the flow is nearly constant, two factors which indicate that the springs are not dependent on the local surface water for their supply.

The existence of this porous bed and the evidence that it carries much water favor the belief that other water-bearing beds are associated with the rocks underlying the valley; while the synclinal

[a] George Davis Louderback has well expressed this idea of the thinning out and overlapping of successive lava sheets, in a paper entitled "Basin range structure of the Humboldt region" (Bull. Geol. Soc. America, vol. 15, 1904, pp. 302–303). In this paper he says: "Volcanic rocks that are the successive products from several vents are likely to be very irregular in their areal distribution and order of superposition. The failure of a later to cover completely an earlier, or the overlapping of a later over an earlier, or the failure of a later to overlie an earlier at all, lead to some confusion, and make it difficult and sometimes impossible to arrange them in historic sequence."

structure favors the belief that this water is under sufficient pressure to yield flowing wells when the water-bearing beds are properly tapped.

CONCLUSION.

Although Catlow Valley is 400 or 500 feet higher than the other valleys of Harney County, its climate is said to be milder than that of the lower ones, and it is claimed that precipitation within it is somewhat greater. Possibly the bluff along its eastern side protects it from the cold storms that sweep over the more exposed valleys.

There is little available surface water, but the indications favor a plentiful supply of shallow ground water, both for domestic use and for irrigation by means of pumping plants. It is probable that flowing wells of small yield may be obtained in the unconsolidated material near the margins of the alluvial fans on the eastern border of the valley. Deep drilling for flowing artesian rock water is also warranted by the structure and other favorable conditions, and it is probable that a valuable supply of water for irrigation may be developed from the deep-seated sources.

Except in limited alkaline areas in its lowest parts, the soil conditions in this valley seem good, so that when it has become settled and transportation facilities are improved it should support a well-to-do agricultural and stock-raising community.

ALVORD BASIN.

LOCATION AND EXTENT.

The Alvord basin extends along the entire eastern base of Steens Mountain and southward along the Pueblo Range a short distance into Nevada. Throughout its greater extent it has a width of 6 to 10 miles, but in its northern portion its continuity is interrupted to some extent by hills, and the valley portion is much narrower. The elevation of the valley land, as nearly as could be determined by aneroid barometer, is about the same as that of Harney Valley—between 4,100 and 4,200 feet.

SOIL AND VEGETATION.

In the northern part of the basin much of the surface is covered with gravel and alluvium that have been brought down by the streams from Steens Mountain. These materials have formed great alluvial fans, which have built up the divides that limit the basins of Juniper and Mann lakes and separate the drainage areas of these water bodies from each other and from that of Alvord Desert. Wildhorse Creek has also brought down and spread along its lower course a layer of gravel, on which there is a rank growth of sagebrush. Near the

mouth of the canyon of Trout Creek, along the east side of Alvord Valley, the stream wash has also built a considerable extent of gravelly bench land. Nearly all of this gravelly land is tillable, and would be valuable for farming if water were applied to it. A narrow strip along Wildhorse Creek and a much larger area along lower Trout Creek yield crops of marsh hay, as do also an extensive acreage of the Alvord ranch and smaller meadows at Mann and Juniper lakes. On the Alvord ranch considerable alfalfa is also raised, and about 5,000 bushels of barley are threshed each year. But there is much waste land in the basin. From the playa of Alvord Desert a wide belt of greasewood land extends southward, includes the land surrounding Alvord Lake, and extends 5 or 6 miles south of the borax works. Along Pueblo Creek, also, for 4 or 5 miles south of Tumtum Lake, there is a band of greasewood land, a couple of miles in its maximum width.

SETTLEMENT.

At Denio and at Andrews there are post-offices and small stores, and a few homes. Throughout the basin there are homesteads wherever there is water for irrigation, but most of the watered land, by which is meant most of the wild-hay land, is controlled by the large cattle companies. Recently a few new settlers have filed on homesteads south of Juniper Lake, but this was the only one of the several areas of vacant sagebrush land in this basin that was beginning to be settled in the summer of 1907. A couple of miles south of Andrews, Mr. A. Miranda has a number of acres of alfalfa, which in early summer are irrigated by water from the mountain stream on the west. A few miles farther south, Mr. A. H. Hollis has a few acres of irrigated meadow; while in the small valley along Trout Creek, near Flagstaff Butte, water is available for irrigation, and much alfalfa is grown. On Little Trout Creek, about one-half mile above its junction with the larger stream, Mr. J. C. Beatty has a small acreage, which has been brought under a higher state of cultivation than any other ranch noticed in this region. As his ranch is a good example of what can be done in this section where water is available, the following statements were obtained concerning the crops he raises. In the narrow strip along the creek that has been brought under irrigation he has a number of acres of alfalfa, from which three cuttings a year are harvested. Nearly all vegetables can be grown, and his potato patch of $2\frac{3}{4}$ acres has yielded 245 bushels to the acre. In this locality it is best to plant vegetables after the first week in May, so that they may escape the late killing frosts. Apples and other hardy fruits do well, but the late-blooming varieties have been found to be the best. Plate V, *A*, shows Mr. Beatty's ranch and the extent of the cultivated land on each side of the stream.

MINERAL DEPOSITS.

For the last nine or ten years borax has been shipped from the works near the hot springs south of Alvord Lake. Of the deposit here Joseph Struthers says:[a]

> The marsh deposits of sodium borate in Harney County, which extend over 10,000 acres south of Lake Alvord, have been operated during the last few years, and the refineries have produced a yearly output of approximately 400 short tons of refined borax, which is carried by mules to Winnemucca, on the Central Pacific Railway, whence it goes to Chicago, St. Louis, and occasionally to San Francisco. The Rose Valley Borax Company owns 2,000 acres of the richest portion of the deposit close to the lake. The ground is level and treeless and is incrusted with a layer of sodium borate several inches in thickness, which contains also sodium carbonate, sodium sulphate, sodium chloride, and other salts. During the summer the loose surface deposit is shoveled into small heaps and is replaced by a second incrustation within a comparatively short time. As no mining is done in winter, sufficient material is collected in summer to furnish a supply to operate the refining works throughout the entire year. The crude mineral, containing from 5 to 20 per cent of boric acid, is shoveled into tanks of boiling water, and chlorine or sulphuric acid is added to decompose the alkali salts, and thus free the boric acid. After twenty-four hours the clear supernatant liquor is drawn off into crystallizing tanks and cooled, yielding white pearly scales of high-grade boric acid, and a mother liquor, which is used repeatedly if it contains a sufficient quantity of sodium salts to warrant a separate treatment.

In the collection of the alkali crust Chinamen have been employed chiefly. This crude deposit is first scraped into windrows with shovels and then loaded into wagons and hauled to the works. Sagebrush is used as fuel under the dissolving tanks. The refining plant consists of two of these tanks, of 6,000 and 8,000 gallons capacity, respectively, and 24 crystallizing tanks, each of 1,200 gallons capacity. The crystallized product of borax is sacked and hauled to Winnemucca, Nev., by 16-mule teams.

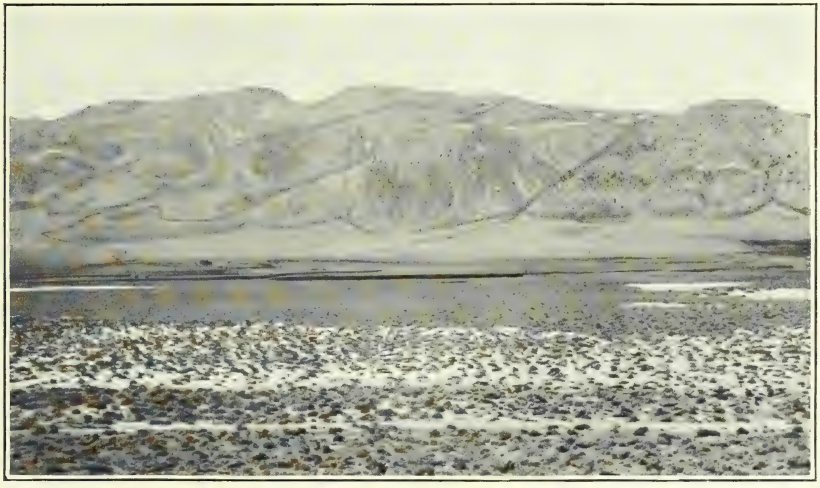
As has been stated in an earlier part of this paper, new interest has been aroused within the last few years in copper prospects on Pueblo Mountain and the neighboring slopes, but up to the fall of 1907 no extensive development had been undertaken. The metal seems to be associated with the porphyries and the granitic series of rocks that form the Pueblo Mountains.

SURFACE WATER.

Trout Creek, the largest stream in this basin, rises in the hills of the southeastern corner of the county, enters Alvord Valley from the east, and flows northward along it. Half a mile above the mouth of its canyon the rock walls closely approach each other, and open out above into a little valley that forms a very good reservoir site. The advantages of a reservoir here for the storage of water for irrigation have long been realized, but no detailed survey of the site had been

[a] Struthers, Joseph, Borax: Mineral Resources U. S. for 1901, U. S. Geol. Survey, 1902, pp. 870–871.

A. J. C. BEATTY'S RANCH ON LITTLE TROUT CREEK.



B. ALLUVIAL FANS ON WEST SIDE OF ALVORD VALLEY, NEAR MANN LAKE.

made at the time of this reconnaissance. It is said that if a dam 100 feet in height were built at the narrowest part of the canyon it would form a water body about half a mile long and perhaps 300 or 400 yards wide. At the lower end of a larger valley about 3 miles farther upstream there is another good dam site, but the reservoir that would be formed here is, on casual examination, of much greater capacity than the inflow could fill advantageously, while the valley that would be submerged is occupied by two or three farms.

Nearly all the other streams of the Alvord basin are on its western side and are fed by the springs and melting snow of Steens Mountain. This water finds its way to the few lakes or else sinks in the alluvium and marsh lands before reaching these water bodies.

On the talus slopes of the Steens Mountain scarp there are numerous surface springs which are fed mainly by melting snow, and there are also a few cold springs supplied by water from a source not so direct. Of these may be mentioned that known as Summit Spring, No. 236, on the road between Juniper ranch and Mule ranch, and a larger spring on the road between Alvord and Catlow valleys. On the lower slopes also there are a few springs along the canyon sides. In at least one place, at the home of Mr. A. H. Hollis, 6 miles south of Andrews, a seepage spring has been developed by tunneling, so as to furnish a supply of water for domestic use. There are also a number of hot springs in this valley, of which those near the borax works south of Alvord Lake are the largest and hottest. About one-quarter mile north of the works there is a series of vents along a line one-quarter mile long, in some of which the water is near the boiling point. At the borax works there is a pool about 275 yards in diameter, known as Hot Lake. It is on a low mound surrounded by greasewood and salt-grass land, and the edge of the pool is bordered by a hard crust of carbonate deposit. The water rises from the bottom of the pool through several vents and discharges through a ditch, with a fairly constant flow of between 75 and 100 miner's inches. The temperature of the water varies, however. When measured in September, 1907, where it discharges from the pool, it was 97° F., while seven weeks later the temperature at the same place was 82° F. The water is used in the boiling tanks of the borax works and to some extent in irrigating a field of salt grass east of the pool.

On the western side of Alvord Desert there is another group of hot springs, which have a temperature of about 168° F. Their water sinks in the barren land of the desert after flowing a few hundred yards through a salt-grass area.

On Trout Creek, at the base of Flagstaff Butte, there is a fourth hot spring. Five or six vents at this place yield a total of perhaps 5 miner's inches of water, which rises with a temperature of 128° F.

Advantage is taken of the temperature of this water during the sheep-dipping season, when it is used in preparing the dip.

Although its temperature is but slightly above that of the ground water, a spring on Mr. A. C. Bustamante's place, about 2½ miles southeast of Andrews, is mentioned here with the hot springs, inasmuch as its location with respect to the mountain block that terminates in Serrano Point suggests that its existence is due to the dislocation that produced that block, and that its source, like that of warmer springs, is deep-seated water that rises along fault planes, or shallower water heated by the proximity of masses of lava beneath the surface, that have not yet cooled to a normal temperature.

The lakes of Alvord Valley are of course dependent mainly for their supply upon the inflow from streams and springs. Alvord Lake, the largest of these, is an alkaline body that changes much in size with the season. In years of great precipitation, as has been previously stated, it overflows northward to the great playa of Alvord Desert. Tumtum, Mann, and Juniper lakes contain comparatively fresh water, but as each occupies the lowest part of the locality in which it lies the water has not been used for irrigation. Their shores are steeper than those of Alvord Lake, and hence they do not fluctuate so greatly in areal extent. Ten Cent Lake, at the northern end of the valley, receives its supply in large part through ditches that bring to it water from the slopes to the southwest. It is thus made a storage reservoir for water that in summer is conducted southward through a ditch to irrigate land on the Juniper ranch.

GROUND WATER.

As in the other valleys, water is obtained at a shallow depth in the alluvial filling of Alvord Valley, and in the wells that were visited it is of good quality, since it is derived mainly from the snow of Steens Mountain.

The streams that flow down the Steens Mountain scarp have built alluvial fans, in which conditions are favorable for the existence of water under pressure; and the presence of such water is shown in several wells. Fourteen flowing wells, practically all that had been sunk in the valley up to that time, were noted in the fall of 1907.

All of these flowing wells were bored, and work in several unsuccessful ones had to be stopped when coarse gravel was encountered. Three wells, Nos. 65, 66, and 67 (Pl. III), on Mr. A. Miranda's place, 2 miles south of Andrews, have a diameter of only 2 inches, and as the head is slight the flow is small and is used only for domestic purposes and for watering cattle. About 4 miles farther south, in meadow land belonging to Mr. A. H. Hollis, there are six flowing wells, Nos. 70 to 75, inclusive, which are 6 and 7 inches in diameter

and yield a total flow of about 25 miner's inches. The water is used to irrigate the grass land immediately adjacent. About 6 miles north of Denio there is a 6-inch well (No. 81) belonging to Mr. J. Thomsen. It was flowing perhaps 2 miner's inches in September, 1907, but little attempt had been made to utilize the water. This well is near the channel of Pueblo Creek, and on the western edge of the alkaline land that extends along its course. Near the edge of the marsh land south of the Alvord ranch (at No. 61) an artesian flow was obtained in the spring of 1907 by Mr. S. Alberson. The other flowing wells of this valley are small ones, only 2 or 2½ inches in diameter, and their flows were not being put to any use at the time of this examination. All of these flowing wells have been obtained in a narrow strip of land close to the center of the valley, and their artesian head is slight. Two wells, Nos. 68 and 76, which were bored a little farther from the trough of the valley than the successful ones, failed to yield flowing water, though water rose in them to within 3 and 4 feet of the surface, respectively. Two other wells near Andrews, Nos. 63 and 64, failed to obtain artesian flows, and the water is said to have risen in each only a foot or two above the depth at which it was struck. The artesian area is thus seen to be limited to a narrow belt along the lowest portion of the valley, and the greater part of this land is not suitable for cultivation, owing to its alkaline quality. Near Denio only one flowing well (No. 82) was noted, and it seems to be a developed spring rather than an artesian well.

The locations of the wells that were noted in this valley are shown on Plate III, and other facts concerning them are listed in the following table:

Wells in the Alvord basin.

No. of well.	Owner or location.	Class of well.	Method of lift.	Depth to water.	Total depth.	Diameter.	Remarks.
				Feet.	*Feet.*	*In.*	
59	South end of Juniper Lake.	Dug	Bucket and rope.	10	.....	.....	
60	F. Miranda's stage station.	...do.....	Wheel and bucket.	12	.....	.....	
61	S. Alberson, sec. 28, T. 34 S., R. 34 E.	Bored...	Flows.....	6	84	6	Artesian flow at 47½ feet; barely flows.
62	Hotel, Andrews.....	Dug.....	Wheel and bucket.	20	.....	.....	
63	1 mile southeast of Andrews.	Bored...	Windmill.....	14	.....	.....	
64	.....do.....	...do.....	.....do.....	6	.....	.....	
65–67	A. Miranda, 2 miles south of Andrews.	...do.....	Flow.....	.....	(a)	2	Cased only part way; flows are about ½, ¾, and 1 miner's inch.
68	¼ mile south of No. 65...	...do.....	Not used.....	3	202	.....	Unsuccessful boring for artesian flow; water under pressure struck at 117 feet.
69	Ed. Carlson, 1 mile southeast of No. 65.	...do.....	Flows.....	.....	183(?)	.....	Unused.
70	A. H. Hollis, 6 miles south of Andrews.	...do.....	.....do.....	.....	150	6	Flow, ½ miner's inch; temperature, 68° F.

a Thought to be between 100 and 200 feet.

Wells in the Alvord basin—Continued.

No. of well.	Owner or location.	Class of well.	Method of lift.	Depth to water.	Total depth.	Diameter.	Remarks.
				Feet.	*Feet.*	*In.*	
71	A. H. Hollis, 6 miles south of Andrews.	Bored ..	Flows.....	.....	50–100	6	Flow, 6½ miner's inches; temperature, 72° F.
72	.....do.....	...do.....	.....do.....	.....	50–100	7	Flow, 6½ miner's inches; temperature, 71° F.
73	.....do.....	...do.....	.....do.....	.....	50–100	7	Flow, 4 miner's inches; temperature, 64° F.
74	.....do.....	...do.....	.....do.....	.....	50–100	7	Flow, 3½ miner's inches; temperature, 68° F.
75	.....do.....	...do.....	.....do.....	.....	50–100	7	Flow, 4 miner's inches; temperature, 68° F.
76	A. H. Hollis, ¼ mile south of No. 75.	...do.....	Not used.....	4	170	6	Unsuccessful boring for artesian flow.
77	Mr. Doane, sec. 3, T. 39 S., R. 33 E.	...do.....	Windmill.....	20	.....	.....	
78	Mr. London, east of No. 77.	...do.....	Not used.....	3	(*a*)	.....	Unsuccessful boring for artesian flow.
79	Ed. Catlow, sec. 14, T. 39 S., R. 33 E.	...do.....	Pitcher pump	5	.....	.....	
80	Mr. Johnson, in slough south of Tumtum Lake.	...do.....	Flows.....	.....	23	2	Flow 2 or 3 miner's inches (reported.)
81	J. Thomsen, 7 miles north of Denio.	...do.....	.....do.....	.....	38	6	Flow about 2 miner's inches.
82	2 miles north of Denio...	...do.....	.....do.....	.....	.....	.....	Small flow, possibly a developed spring.

a Said to be over 200 feet deep.

In December, 1908, after the above list was compiled, Mr. J. H. Neal reported that he had drilled a well in the northern end of the basin, in T. 29 S., R. 36 E. The material passed through was mainly "cement" gravel and clay, to a depth of 435 feet. Here a layer of sand was encountered, in which a supply of water, 66° F. in temperature, was obtained, which rose within 86 feet of the surface.

Although strong supplies of water similar to this may be obtained in other parts of the Alvord basin, which will be of value for pumping purposes, it is not probable that flowing artesian wells can be obtained in the higher portions of its cultivable lands.

In January, 1909, Mr. Neal also reported that two small flowing wells had been obtained by Mr. Tudor, about 2 miles south of Juniper Lake. One of these is only about 20 feet deep, and has a flow sufficient to fill a 1-inch pipe without pressure. The other is about 70 feet deep, is cased, and yields two or three times as much water as the shallower one.

It is probable that a few small flowing wells can be obtained east and northeast of Denio, near the course of Pueblo Creek, but it is in the portion of the valley between Alvord ranch and Juniper Lake that the possibilities of development by means of shallow flowing artesian wells seem the greatest. This land is composed mostly of alluvial gravel, and is covered with sagebrush. In by no means all of it is there probability of obtaining flowing wells, but along the

center of the valley for 3 or 4 miles south of Juniper Lake, and along the west side of the valley between Mann Lake ranch and the Alvord ranch, artesian flows can probably be obtained from wells sunk in the alluvium near the margins of the fan deposits. The development of these fans near the Mann Lake ranch is shown in Plate V, *B*.

ROCK-WATER CONDITIONS.

On his first visit to southeastern Oregon, Russell[a] considered Steens Mountain to be a great fault block, at the east base of which lies Alvord Valley. After later study of its structure he was inclined to believe it "the western slope of a great anticline,"[b] or at least that in general the structure is anticlinal, but that faulting and also deep erosion have given the present topography to the mountain and to the valley and hills along its eastern base.[c]

This latter hypothesis seems to be the more probable—that the structure is a great low anticline that has been extensively faulted, rather than a great monoclinal block. The Steens Mountain scarp seems to be unquestionably of fault origin, and the blocks within the northern part of Alvord Valley appear to be monoclinal fault blocks rather than erosional remnants; but east of the valley the rocks dip gently eastward, in agreement with the assumption that they belong to the eastern limb of a great low anticline of which the westward-dipping beds of Steens Mountain form the other limb. The eastern portion of the geologic cross section, on Plate III, shows the structure of the valley at the north end of Alvord Desert, where the faulted anticlinal character is best shown.

There is little chance of obtaining artesian flows by deep drilling in this valley. The extensive faulting that has taken place prevents rock water from being stored under pressure in its central and southern portions, while in its northern portion, even if extensive faulting has not taken place, the anticlinal structure does not admit of the collection of deep-seated water.

RÉSUMÉ.

In summing up the agricultural conditions in Alvord Valley, and its further possibilities, the following statements may be made: The climate is milder than in the higher and more open parts of the county, because it is protected even more than Catlow Valley by a great escarpment. The valley contains much fertile land that is still

[a] Russell, I. C., A geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, p. 439.

[b] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Supply Paper U. S. Geol. Survey No. 78, 1903, p. 43. See also p. 23 of the same paper.

[c] See also Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903, pp. 15, 68.

unoccupied, but there is also a great amount of worthless land within it. Water is easily obtained by sinking shallow wells, and except in the lowest lands it is of good quality. In certain parts shallow flowing wells have been obtained, and in certain other restricted areas that have been named it is probable that flowing water can be developed. The rainfall is usually sufficient to raise dry crops of grain, but without water for the irrigation of other crops agriculture can hardly prove successful. The section is remote from market, and probably will be for a number of years to come; but the local consumption of hay and grain is increasing, and there is usually a good demand by sheepmen and cattlemen for such produce during the winter months.

WHITEHORSE BASIN.

DESCRIPTION.

The Whitehorse drainage basin lies east of Alvord Valley, between it and the plateau country that drains northeastward to Owyhee River. The southern slopes of this basin rise to the Whitehorse Mountains, while on the east and west gentler slopes form its sides. The northern part of the basin widens out to a flat alluvial valley, which merges into the higher plateau country that stretches toward Barren Valley, in Malheur County.

At the Sand Gap, in its northwestern end, only a low divide separates this drainage basin from that of Alvord Valley. Toward the northeast a wide arm of the valley extends for a few miles, but no evidence was seen that indicated an opening out of the valley in that direction, nor that flood water has, during recent years at least, extended very far along this northeastern arm.

SOIL.

In the southwestern part of the basin the soil is derived mainly from light-colored tuff and volcanic ash, but near the stream channels it is more gravelly. On the Whitehorse ranch there are some 3,000 acres of wild-hay land, upon which practically all the available surface water is used. Northward beyond the limits of this meadow there is much cultivable sagebrush land, but on the west side of the basin the soil is dryer and probably somewhat alkaline, as it supports only a scanty growth of greasewood.

SETTLEMENT.

The Whitehorse ranch controls all the meadow land of the valley, and from it approximately 3,000 tons of hay, or a ton to the acre, is gathered each year. In the fall the cattle from the surrounding range

are rounded up here to pasture during the winter, and are fed from the stacks during the more severe weather.

The only habitations in the valley land during the past year were at this ranch; though in the southern part of the basin, along the upper course of Willow Creek, there were two or three small farms where water was available for irrigation.

SURFACE WATER.

There are two streams in the Whitehorse basin, Willow and Whitehorse creeks. These rise in the hills to the south and flow in a direct course toward its northern end. In late summer Whitehorse Creek is nearly dry, but Willow Creek enters the lowland with a flow of 50 to 75 miner's inches. Through the southwestern part of the basin, which is a wide, sagebrush-covered, gently sloping valley, storm-water channels carry the run-off to Willow Creek.

In this southwestern portion there are two localities of springs. At the western one (No. 244, Pl. III) an acre or more of ground is kept wet by the seepage from numerous small vents; while half a mile farther east four springs a few yards apart, with a combined flow of 3 or 4 miner's inches, discharge water close to 100° F. in temperature.

GROUND WATER.

During harvest season, water for the haying crews is obtained throughout the meadow land of the Whitehorse ranch from dug wells a few feet in depth. At the ranch house, water stands about 15 feet below the surface during the summer. Wells in nearly all other parts of the agricultural lands should also reach water at shallow depths.

Whitehorse and Willow creeks have not formed alluvial fans of noticeable extent, because for most of their lower courses they have relatively gentle grades, and do not debouch from steep canyons upon a flat valley. Hence, conditions do not favor the storage of water under pressure beneath the marsh land of the lower courses of these streams, as they do in portions of the Alvord basin.

From the vicinity of Flagstaff Butte the valley floor slopes to the northeast, but the deposits over this area are bedded volcanic ash rather than alluvium, and the water supply to this surficial material is very limited. It is possible that wells sunk in the lower part of the valley, west and southwest of the Whitehorse ranch, might strike water in the alluvial and tuffaceous material under sufficient head to yield artesian flows, but the chances do not favor the existence of such water in these shallow deposits.

GEOLOGIC STRUCTURE.

Structurally the Whitehorse basin is synclinal, for from the south the bedded lavas composing the mountain slopes dip toward it, and from the east and from the west the rocks also dip gently toward its valley land. A few miles south of the Whitehorse ranch a low rocky divide that separates the channels of Whitehorse and Willow creeks narrows the alluvial land to a belt along Willow Creek and partially divides the topographic basin into an upper and a lower valley. While in this middle portion there may also be some constriction of the structural basin, the attitude of the rocks, where observed, indicates that it is not divided into two separate basins.

ROCK WATER.

That tuffaceous layers are interbedded with the lavas is shown where they are exposed south of Flagstaff Butte and in other places west of the valley, and by layers from which springs issue that are exposed east of the Whitehorse basin, in Oregon Canyon.[a]

The hills to the south furnish a catchment area in which water may penetrate to the deeper rock layers; so that the favorable conditions of structure, pervious beds, and source of supply, necessary for the existence of water under pressure, seem to be fulfilled in this basin. Hence it is very probable that wells drilled to a considerable depth and properly cased will yield artesian flows. A possibly unfavorable condition is the low elevation of the northwestern rim at the Sand Gap, but as the supply of water to the deep layers probably comes mainly from the south it is not considered that this low place seriously affects artesian conditions within the basin. Since it is the lowest, the northern part is that most favorable to the existence of artesian water, but in the southern portion also, in the neighborhood of the springs that rise near the road, artesian conditions probably obtain, as was pointed out by Russell[b] several years ago.

The depth at which an artesian flow in this basin may be expected can not be foretold even approximately, since no deep wells have been sunk in the region. It seems, however, judging solely from the evidence furnished by the springs in Oregon Canyon, that such water should be found within a depth of 1,000 feet. The warm springs in the southern part of Whitehorse basin are possibly artesian in character, and their water may derive its high temperature by coming from deep sources, but it is thought that their abnormal temperature is more probably due, in part at least, to the proximity of heated rock

[a] See Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Supply Paper U. S. Geol. Survey No. 78, 1903, p. 43.

[b] Op. cit., p. 44.

below the surface. Flagstaff Butte has the appearance of being either a center of effusion or an intrusive mass, and in its vicinity the underlying rocks may still have a higher temperature than is normal for the depths at which they lie. The hot spring at the south base of Flagstaff Butte is also evidence of a disturbance of some sort that has given rise to increase of temperature in the rocks underlying this locality.

MALHEUR RIVER DRAINAGE AREA.

SURFACE WATER.

The portion of the area shown on the reconnaissance map (Pl. II) that lies east of the Harney basin and north of the Alvord basin is drained by a number of streams tributary to Malheur River. The northern slopes are drained in part by Stinkingwater Creek, an intermittent stream, and in part directly into Middle Fork of Malheur River by small drainage courses. The southern portion of the area is drained by Crane Creek and its tributaries. This stream in its lower course is known as South Fork of Malheur River, and joins Middle Fork at Riverside. Most of the tributaries to Crane Creek flow during only a part of the year, while this creek itself is dry in summer along portions of its upper course. From the south, Camp and Indian creeks receive the run-off from a considerable area that lies between the Harney and Alvord basins, and after uniting flow through several miles of meadow land to the valley of Crane Creek.

A number of springs issue from light-colored tuffaceous beds along the canyon sides of Crane Creek. At least one of these, No. 253, has been dug out and enlarged, and furnishes water for domestic use, yielding a constant flow of perhaps two gallons a minute. Other similar springs along the edge of the creek valley flow in small volume during the summer. Several warm springs also rise along the lower course of Crane Creek, but these have been sufficiently described in the general discussion of the surface waters of the region (p. 38).

CULTIVABLE LAND.

The cultivable land of this part of Harney County is confined almost wholly to the courses of the larger streams. Warm Spring Valley, along Middle Fork of Malheur River, is over a mile in width and 5 or 6 miles long. A great part of it supports growths of rye grass and meadow grass, and on the stock ranches that control most of the land some alfalfa is also raised. The Malheur project of the United States Reclamation Service, which contemplated the irrigation of land along the lower course of the stream, included the construction of a dam at the lower end of this valley, which would convert nearly the whole valley into a lake. This was called in the preliminary

surveys the Harper Reservoir. In the spring of 1908 work had not been extended beyond these preliminary surveys, and construction had been indefinitely deferred, owing to the high estimated cost per acre of the project.

On upper Crane Creek there is an area of bottom land in which are two or three ranches, and on these ranches the summer flow of the stream is used for irrigation. A short distance below the point where the road through Crane Creek Gap crosses the stream valley the canyon walls approach each other, leaving only a narrow strip of bottom land along the creek for a distance of 3 or 4 miles. Near the mouth of Gorman or Alder Creek the valley widens again, and from this point to a couple of miles below the mouth of Coyote or Little Crane Creek the alluvial land is from a quarter of a mile to nearly a mile in width. Part of this bottom produces wild hay and on a part grain is raised, but the greater share of it was still covered with sagebrush at the time of this examination. On the two or three farms along this lower valley the stream water is used to some extent in irrigating small gardens and orchards. The lower 6 or 8 miles of the part of this stream valley that is shown on the reconnaissance map (Pl. II) is floored with basalt, and there is little tillable land in it.

From the junction of Camp and Indian creeks to near Venator post-office, a distance of 5 or 6 miles, the flood water of these streams has produced a stretch of marsh land, along which there are a few hay ranches. Crane Creek and its tributaries, with the exception of Camp Creek, which will be spoken of later, furnish a supply of water which, if stored, would probably be sufficient to irrigate most of the cultivable land along their courses.

STRUCTURAL CONDITIONS.

As there are warm springs along the lower course of Crane Creek, it may be well to speak of the rock structure in its relation to deep-water conditions in this area. On this subject Russell's notes on the structure along Crane Creek are quoted below:[a]

> Crane Creek receives Coyote and Gorman creeks as tributaries from the north. These two creeks and the upper portion of Crane Creek, above the abrupt bend in its course where the road leading to Malheur Lake leaves it, flow south in nearly parallel valleys, due mainly to faulting, and enter a large valley with bold walls, which trends about east and west. This larger valley has several peculiar features which at once attract attention. In a general view it appears as a deep stream-cut valley, about one-half mile wide, leading directly through the hilly country it traverses, and affording a low-grade pass to Harney Valley. The impression is that it was formed by a river which escaped from Harney Valley. * * *
>
> In traversing the Crane Creek Pass, as it may suggestively be termed, from east to west, one ascends Crane Creek, which has a well-defined gradient, until about 10 miles below its ultimate source, where a steep ascent of about 100 feet leads to a divide,

[a] Russell. I. C., Preliminary report on the geology and water resources of central Oregon: Bull. U. S. Geol. Survey No. 252, 1905, pp. 38–39.

or rather a crest that would be a divide if surface waters were present, separating the slopes on the east draining to Crane Creek from the slopes on the west draining to Malheur Lake. On the west the floor of the pass is approximately level. Throughout the two portions of the old valley the width is about one-half mile, and the bordering escarpments are bold and steep, and in general 200 or 300 feet high. The valley is clearly the result of stream erosion, and is a part of the record inscribed on the land, showing formerly greater precipitation than now. The divide which crosses the course of the valley from north to south is due to movements in the rocks subsequent to its excavation, and is of the nature of a fault, the west side of which has been upheaved in reference to its eastern side. Other illustrations of faulting and tilting are present in the same region, and are suggestive of the causes which produced changes in the direction of flow of the modern streams in respect to their former and larger representatives.

This region, near the eastern border of Harney County, shows numerous evidences of having been faulted; and it is probably along fault planes or zones that the water of the springs in Warm Springs Valley (along Malheur River) rises. There are similar springs at Mr. H. C. Luce's, in sec. 20, T. 24 S., R. 37 E., which yield 6 or 7 miner's inches at temperatures of from 106° to 143° F. The water of Mr. Dennean's spring, in sec. 2, T. 25 S., R. 36 E., probably issues through a fissure or other vent from an underlying porous bed. The existence of such beds carrying water under pressure is so uncertain in this region of faulted structure that it would be a very uncertain undertaking to drill for flowing wells should a greater supply of water than the streams furnish ever be needed.

ANDERSON VALLEY.

DESCRIPTION.

In the southern part of the area draining to Malheur River, the course of Camp Creek above its junction with Indian Creek lies for a number of miles in a wide flat valley known as Anderson Valley. The western and northern portions of this valley are rocky, and except for a few playas are not cultivable. Along the southern side of the valley, however, there is much agricultural land. During the past few years several fields have been cleared in this section, and wheat and rye have been raised.

SURFACE WATER AND SHALLOW WATER.

Camp Creek, the main drainage channel through this valley, is dry during the summer months in years of ordinary rainfall. Mr. James Mahan, who owns the Mule ranch, has built an earth dam 24 feet high and 130 feet long at the base across Camp Creek a couple of miles below his ranch. This forms a storage reservoir with a capacity estimated at about 1,800 acre-feet. In the spring the supply from Camp Creek is said to be ample to fill this. During the past summer an irrigating ditch was being extended from this reservoir eastward along the edge of the valley, with the intention of putting much of the land under irrigation.

Few wells had been sunk in this valley when it was visited, as few people had yet filed on land in this locality. Of the four wells marked on Plate III as within it, No. 90 was dug in the gravel wash of a wet-weather stream, where water was easily obtained; the one at Mule ranch was sunk in the bottom land of Camp Creek, where the ground-water level is only about 4 feet below the surface; while in the western part of the valley wells Nos. 86 and 87 reached basalt only 3 or 4 feet below the surface, and failed to reach water at the depths of 10 and 27 feet, respectively, to which they were sunk in the hard rock.

It is probable that drilled wells can reach water within a reasonable depth in this part of the valley, perhaps within 100 feet, but it is hardly practicable to dig wells through the basalt that underlies the playas of the central part of the valley.

During the early part of 1908 a well (No. 88) was being drilled by Mr. J. R. Jenkins near the north base of Riddle Mountain, near the center of sec. 14, T. 28 S., R. 34 E. The following record of material passed through, as reported in February, 1908, indicates a succession of basalts and tuffaceous beds, such as are exposed along several escarpments in this region:

Record of Jenkins well, near Riddle Mountain.

	Feet.
Cement gravel	0–95
Black lava rock	95–155
Brown sand rock and hard cement gravel in stratas of 5 and 10 feet	155–205
Clay and sand (white sand rock, brown and black, in strata of 10 to 20 feet), with very hard streaks	205–335
Clay and shale	335–425
Blue clay, with the odor of sulphur	425–455

Water at a temperature of 66° F. was struck in this well at a depth of 70 feet, but it rose above this depth little if at all, indicating that it was under no appreciable pressure. At 300 feet this water was lost, but on drilling deeper another supply was struck that rose 300 feet. At last accounts (August, 1908) the water stood 200 feet below the surface. This well is situated on the mountain slope, considerably above the valley floor, and hence is not a fair test of conditions in the valley proper.

On the slopes to the south of Anderson Valley numerous springs that issue along the sides of steep canyons may be in part surface springs, though the greater share of their water probably comes from tuff beds that have been cut across by the streams. Water does collect under pressure in these beds, but it is doubtful if at any point on the lower slopes the head developed is sufficient to bring it to the surface when tapped by a drilled well; for the pressure is relieved by

the issuance of the water as canyon springs or by its escape northward and downward within the beds.

ARTESIAN CONDITIONS.

As previously stated, lava belonging to a more recent period of effusion than that of the Steens Mountain basalt covers a great part of the floor of Anderson Valley, but the structure of the underlying rock has not been altered by these more recent flows, and it is shown by the attitude of the beds along the sides of the basin. On the south the slopes of Steens Mountain dip beneath Anderson Valley at angles up to 10°; from the north the lava sheets also pass beneath the valley floor; while on the west, over the area of low relief that separates this basin from Harney Valley, the beds are nearly horizontal. The valley lies, therefore, in a synclinal basin whose southern side is much the higher and longer. Its western end flattens out and merges with the structure of the Harney basin, while to the northeast there is an outlet, structural as well as topographical, along the course of Camp Creek.

As elsewhere in this great area of bedded lavas, porous sheets of tuff are associated with the rocks that underlie Anderson Valley. The northern slopes of Steens Mountain are a catchment area for water that can find its way downward through seams and fissures in the harder layers, to these more porous beds beneath. In general, however, the structure of this valley is not favorable to the storage of water under sufficient head to bring it to the surface in drilled wells, for the low western side of the basin, as well as the outlet northward down the valley of Camp Creek, may allow the water to escape in those directions, while the recent lava that floors part of the valley probably issued from fissures beneath it, which are now filled by the congealed rock and form dikes that greatly influence the circulation of deep-seated water in their vicinity.

It is possible that along the southern border of the valley the change from a dip of 10° to near horizontality may be sufficient to produce artesian head in deep-seated water, especially if the water-bearing bed becomes thinner beneath the valley than it is in the mountain slopes, as such constriction gives greater head to the water; but the conditions for obtaining flowing water in any part of the valley are not favorable enough to warrant the drilling of a test well.

TEMPERATURE OF UNDERGROUND WATER.

In a study of the water supply of a region the temperature of water from wells and springs often suggests the depths from which it rises. Shallow underground water varies somewhat in temperature with the season, but below a depth of about 50 feet the temperature is fairly constant throughout the year, and records of deep wells and borings all over the world have shown that in regions where the rocks have

been long undisturbed it increases about 1° F. for each 50 or 60 feet of increase in depth.

This rate of increase of temperature with depth is often assumed in estimating the depth from which the water of warm springs rises. In regions of sedimentary rocks and simple structure some reliance may usually be placed on it, but in areas like southeastern Oregon, where the rocks are nearly all lavas, and where abundant evidence exists of very late volcanic activity, other factors influence the temperature of underground water, and it is doubtful if such evidence has value in estimating the depth of artesian water horizons.

There may be several springs in the area studied, for instance those about 3 miles south of Burns and the warm springs near the Double O ranch, whose abnormal temperatures are due solely to the depth from which the water rises. But many others, such as the hot spring on upper Rock Creek, the one near the southeastern end of Harney Lake, and the one on the western edge of Alvord Desert, seem to owe the temperatures of their water to such causes as proximity to underlying rocks that have been heated by enormous pressure and friction along fault zones; to masses of intrusive rock that have not yet cooled; or possibly to residual heat in the lavas themselves. Hence even those springs of the Harney basin region whose temperatures do indicate a considerable depth to the source of the water are not to be regarded as reliably measuring it. Russell [a] used the temperature of the spring north of Harriman as a basis for estimating the depth to the horizon from which it is supplied. Local report, which seems to be confirmed by the discordance between Russell's measurement in 1903 and one made in 1907, indicates that the water of this spring varies in temperature and in volume, and that it is supplied from more than one horizon. It is possible that this water becomes heated largely by rising along a fault plane, where the rocks are above the normal temperature. The spring at the borax works south of Alvord Lake also seems to be supplied from more than one water-bearing horizon, as its temperature varies noticeably, but no series of observations is available to indicate whether this is a seasonal variation or not.

The temperature of shallow well water usually corresponds closely to the mean annual temperature of the region, though, as has been said, that of water less than 50 feet below the surface varies with the season, being a little warmer in summer than in winter. The temperature was noted in most of the wells that were visited, and at this time, in late summer and early fall, was uniformly several degrees above the estimated mean annual temperature. The average temperatures of well water in the sections examined were as follows: At Burns and Narrows, from 51° to 53°; at Riley, Lawen, and near Dog Mountain,

[a] See quotation on page 64.

about 50°, and in Alvord Valley, 54°. The available weather records indicate that the mean annual temperature at Burns is about 43°. In the other localities no records have been kept, but their mean temperature is probably 2° or 3° higher than at Burns.

WELL-SINKING METHODS AND COSTS.

A number of the shallow wells in southeastern Oregon have been dug, since the valley deposits are easily excavated and in most places are sufficiently firm not to require curbing, but most of the wells have been bored. Small domestic wells are easily put down with a 2-inch or 3-inch carpenter's auger welded to a length of rod or pipe, to which other joints can be added as the hole deepens. It may be manipulated by hand alone, but when the string of rod becomes heavy, a tripod and small block and tackle are sometimes used to raise the auger. From 3 or 4 inches to a foot or more may be bored each time the auger is screwed down and lifted. In passing through the drier, more incoherent layers it is only necessary to pour a little water into the hole, so that the material will cling to the auger.

When water is struck, which is in nearly all wells at less than the suction limit of about 30 feet, a length of pipe is lowered into the hole, a pitcher pump is screwed to the upper end of the pipe, and the well is complete. A strainer is seldom placed on the lower end of the pipe, since after a short period of pumping the finer particles of sand are removed from around it, and the remaining coarser material acts as an efficient screen.

In boring wells of larger diameter, of 4 or 6 inches, a cheap and serviceable auger made from a piece of 3-inch or 4-inch wagon tire curled into a spiral is often used. A cutting lip is shaped on its lower end, while a length of pipe is welded or keyed to its upper end. This is used in the same way as the smaller auger, except that on account of its greater weight a small block and tackle is more often used to handle it, and a small platform is constructed from which the instrument is steadied and turned.

At Burns, where layers of firm-textured tuff must be penetrated, many of the wells have been sunk by means of the drop drill or churn drill. These wells are usually made 4 inches or 6 inches in diameter, so as to allow the insertion of a pump cylinder down to within suction limit of the water surface. Few of these wells are cased below the shallow surface coating of soil. The method of sinking is about the same as that described by A. C. Veatch in a recent publication of the Survey,[a] and in an unpublished paper on well-drilling methods, by Isaiah Bowman.[b]

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[a] Geology and underground water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 97.

[b] This paper will be published as a Water-Supply Paper of the U. S. Geol. Survey.

In this method of sinking, the drill bit and string of tools are alternately raised and dropped by a spring pole or a walking beam, operated either by horsepower or by an engine. The percussion of the drill chips off fragments of rock, and by slowly revolving it a circular hole is obtained. When so much material is loosened that it interferes with the action of the drill, the tools are drawn out and the mud is removed by a sand bucket. This consists of a joint of pipe a little smaller than the drill hole, with a valve in its bottom to admit the material. When the hole has thus been bailed out, the tools are again lowered and drilling proceeds.

The deeper wells in Harney County have been drilled by portable rigs, using the regular deep-well drill and walking beam. Such rigs are capable of drilling to a depth of 1,000 feet or more, and will probably prove the most effective means of sinking deep wells in the valleys of southeastern Oregon to tap the deeper rock water.

As stated in considering ground-water conditions in Harney Valley, it is thought that wells sunk to the deeper water-bearing strata of the valley filling will be found to furnish an abundant supply of water by pumping. But it must be borne in mind that the value of this water for irrigation will depend upon the cost of pumping and upon the returns from produce that can be grown.

If the shallower underground water supply of southeastern Oregon is developed to any considerable extent, the sand-bucket method, and especially its modification used in California to sink "stove-pipe" wells, will probably be found best. This method may be briefly described as follows: The casing used is made of heavy cylinders of riveted sheet steel, about 2 feet long and usually from 4 to 16 inches in diameter. It is made of double thickness, one size of cylinder just slipping within another. The sections are placed so as to break joints, and the outer and inner tubes are united simply by denting the casing with a pick. A section of heavier casing, usually 15 or 20 feet long, and provided at the bottom with a sharp cutting edge or shoe, is used as a starter. This is sunk most of its length by digging a pit for it, and upon it the short lengths of casing are added, the whole being sunk by hydraulic jacks buried at the side of the pit, or by steel rails or I beams used as levers to force it down. As the casing is sunk, the material is removed with a sand bucket, which is churned up and down and handled by a rig that differs from the usual type in that the walking beam is short and is placed at the top of the derrick.

In some regions where only unconsolidated material is to be penetrated, wells are quickly and easily sunk by the jetting process. In this process water under pressure is led into the well through a pipe of relatively small size, and directed against the bottom of the hole through a suitable nozzle. The material is thus loosened and car-

ried upward to the surface through the casing, which is sunk as fast as the hole deepens. Although this is a rapid method of sinking in loose material, it is not entirely satisfactory in developing water, and probably will not prove of as great value in the lake valleys of southeastern Oregon as the stove-pipe method; for unless the depth to water-bearing strata is already known they can hardly be detected when struck, and as sinking proceeds they are cased off, so that no evidence is obtained as to the proper depth at which to perforate the casing in order to tap the water-bearing layers.

In regard to the cost of deep wells sunk in the rock layers, the following extract concerning drilled wells in east-central Washington, where the material to be penetrated is similar to that in southeastern Oregon, is quoted from a paper by Calkins:[a]

The charges for well drilling in the southern part of the wheat lands are as follows: In soil, gravel, etc., above basalt, 50 cents a foot; in rock (which is generally in great part massive basalt, though other varieties after the first basalt is struck are not differentiated), $2.25 per foot for the first 300 feet and 50 cents per foot additional for each 100 feet below that depth. Water for the engine, coal, and board for the outfit are furnished by the owner of the ranch.

In the vicinity of Ritzville [Adams County] the terms are slightly higher; for the first 300 feet the charge is there $2.50, and 50 cents higher for each additional 50 feet. On these terms, however, the driller furnishes coal, the cost of which is estimated at about 25 cents for each foot drilled in basalt. In all cases water is guaranteed, and the risk of losing tools (which generally also necessitates abandoning the hole) is borne by the driller. The average cost of a well at these rates is probably not far from $800, though it reaches a maximum of over $2,000.

These wells, in Washington, are usually not cased. In Harney County casing will be necessary at least to solid rock, in order to obtain artesian flows, and this will add another considerable item to the cost of drilled wells. The following prices for casing, in April, 1908, were furnished by the Baker Iron Works, of Los Angeles, California.

Approximate price per foot of lap-weld screw casing, with coupling.

Inside diameter.	Price.	Inside diameter.	Price.
Inches.		*Inches.*	
2 3/4	$0.20	5 5/8	$0.48
3 3/4	.27	7 5/8	.70
4 1/4	.29	8 5/8	.80
4 1/2	.31	9 5/8	1.00

In another publication of the Survey,[b] the expense of sinking wells of the stove-pipe class, in southern California, are given. From it the following table is taken:

[a] Calkins, F. C., Geology and water resources of a portion of east-central Washington: Water-Supply Paper U. S. Geol. Survey No. 118, 1905, p. 60.

[b] Mendenhall, Walter C., Development of underground waters in the eastern coastal plain region of southern California: Water-Supply Paper U. S. Geol. Survey No. 137, 1905, p. 32.

Cost per foot, in cents, of sinking wells of the stove-pipe class.

	4-inch.	5-inch.	6-inch.	7-inch.	8-inch.	9½-inch.	10-inch.
First 100 feet	30	30	35–40	40	40–50	60–65	65
Additional for each 50-foot increase	25	25	20–30	20–35	20–35	20–35	35

Below are prices that were furnished, in April, 1908, by the Baker Iron Works, for sheet-steel riveted double well casing, such as is used in stove-pipe wells:

Approximate cost per foot of riveted double well casing, made up into 2-foot lengths.

Diameter.	Gage.	Price.	Diameter.	Gage.	Price.
Inches.			*Inches.*		
4	16	$0.37	8	16	$0.67
4	14	.45	8	14	.78
5	16	.43	8	12	.93
5	14	.52	9½	16	.79
6	16	.50	9½	14	.92
6	14	.60	9½	12	1.12
7	16	.58	10	16	.81
7	14	.66	10	14	.97

These prices, it must be remembered, are for localities near railroad lines, and in southeastern Oregon the item of freight by team will materially increase the costs. The price of casing also varies with the steel market, so that minor changes take place in it from time to time.

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Compiled from original field notes and all other available data by G. A. Waring in 1908

TOPOGRAPHIC RECONNAISSANCE MAP OF THE HARNEY BASIN REGION, OREGON

Scale

Contour interval approximately 200 feet

Datum is mean sea level

1908

Compiled from original field notes and all other available data by G. A. Waring in 1908

RECONNAISSANCE GEOLOGIC AND STRUCTURAL MAP OF HARNEY BASIN, OREGON

Showing also wells, springs and points at which streams were measured

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 232

UNDERGROUND WATER RESOURCES OF CONNECTICUT

BY

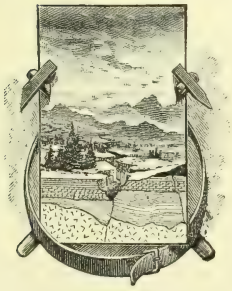
HERBERT E. GREGORY

WITH

A STUDY OF THE OCCURRENCE OF WATER IN CRYSTALLINE ROCKS

BY

E. E. ELLIS



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INTRODUCTION.

The study of the ground water of Connecticut, the results of which are presented in the following pages, was begun in 1903 with the collection and examination of well and spring records and was continued at intervals during 1904 and 1905. During the autumn of 1905 E. E. Ellis cooperated with the author in general investigations, and also made a study of the water in the crystalline rocks. In addition to the report on the special work assigned to him, Mr. Ellis has prepared parts of the chapters on occurrence and recovery of ground water, on character of water, and on well construction and has assisted in compiling data and in preparing illustrations.

For information regarding chemical analyses thanks are due to Prof. Herbert E. Smith, of New Haven, and Mr. George H. Seyms, of Hartford.

The writer wishes to express his great indebtedness to the well drillers of the State, who have freely given much valuable information regarding the occurrence and recovery of ground water. An unusual amount of carefully collected data has been furnished by Messrs. C. L. Grant, of Hartford; F. A. Champlin, of East Longmeadow, Mass.; C. L. Wright, of New Haven; R. L. Waterbury, of Glenbrook; H. B. King, of Hartford; and S. B. Hamilton, of Melrose, Mass.

UNDERGROUND WATER RESOURCES OF CONNECTICUT.

By Herbert E. Gregory.

CHAPTER I.

GEOGRAPHY.

TOPOGRAPHY.

GENERAL RELATIONS.

In its physiographic relations Connecticut is part of the New England plateau, which is characterized by complex groupings of hills composed of igneous and metamorphic rocks; by a few broad valleys cut in softer and less resistant rock material; and by many narrow valleys intrenched in the plateau, and in the main occupied by important watercourses. Other topographic features date from the advent of the great ice sheet of Pleistocene or "Glacial" time, which completely remodeled the New England landscape, accentuating or subduing the previous topography and originating new land forms. The plateau is, however, so dissected as to present the appearance of a region of hills, valleys, and narrow plains, differing in extent and outline.

Viewed as a whole, the surface of Connecticut is a plateau sloping gradually from Cornwall and Goshen southeastward to the Sound. There are no high precipitous mountains or sharply cut canyons, but nevertheless the topography is rugged beyond the average of regions of slight elevation and great physiographic age. High cliffs and rock walls are exhibited in the trap of the central lowland and along certain streams in the highlands, but the hilltops are on the whole rounded and the ridges show a tendency to a north-south alignment. The character of the relief and the prevalence of a north-south arrangement of the hills are well shown by the railroad map of the State, some of the lines occupying north-south valleys, and others crossing the ridges. The Highland division of the New York, New Haven and Hartford Railroad goes through the narrow defile at Bolton Notch, over the pass at Terryville, through the tunnel at Newtown, traversing 119 miles from Putnam to Danbury, though

the direct distance between these points is but 89 miles. Likewise the Central New England Railway, running westward from Hartford, requires 67 miles of track to reach the New York state line, a distance of 44 miles, and crosses the Highlands at Norfolk Summit, an elevation of 1,298.58 feet. Norfolk, 2 miles farther west, with an elevation of 1,210.7 feet, is the highest railroad station in the State. The "Air Line" of the New York, New Haven and Hartford Railroad from Willimantic to Middletown is a short and direct east-west route, but its construction required expensive cuts and fills and bridges, and the grades are unsuitable for heavy traffic. On the other hand, the Northampton division of the same railroad, extending northward from New Haven to the Massachusetts line, is but 1 mile longer than the distance as measured on a map; and the Hartford division, which traverses the lowland from New Haven to Thompsonville, exceeds a direct line by only 2 miles. Even in the heart of the highland areas, the Central Vermont Railway crosses the State in a north-south direction along the winding courses of Shetucket and Willimantic rivers with but 8 miles of track more than the direct distance. In fact, if a railroad were to be constructed from Putnam in a straight line westward across the State the difficulties of operation would be scarcely less than those encountered in truly mountainous districts.

PHYSIOGRAPHIC FEATURES.

Physiographically, Connecticut may be divided into the western highland, occupying that portion of the State west of a line running from New Haven to North Granby; the eastern highland, between Rhode Island and a line through Somers, Rockville, Glastonbury, Middletown, and Branford; and the central lowland, occupying the remainder of the area. (See fig. 1.) These three provinces have characteristic groupings of topographic features which have a direct bearing on the water resources of the State and which have been the controlling factors in its settlement and industrial history.

THE HIGHLANDS.

Western highland.—The western highland increases in elevation from the Sound northward and contains areas of considerable size over 1,000 feet in height. In Barkhamsted the plateau reaches an elevation of 1,400 feet, in Colebrook of 1,500 feet, in Goshen and Cornwall of 1,600 feet, and in Norfolk of 1,700 feet, and it culminates in Bear Mountain, Salisbury, at 2,355 feet. The plateau terminates abruptly on the east and at certain points, as Compounce Pond, the rise from the lowland is precipitous. Differences in elevation and in character and prominence of rock outcrops and the presence of numerous valleys of widely varying depth, width, and extent, give the highlands an appearance of great complexity. They are not,

however, a "region of disorderly hills," but have been controlled in topographic development by geologic forces whose influence was felt throughout southern New England. It was noticed by Percival [a] that the highlands "may both be regarded as extensive plateaus,"

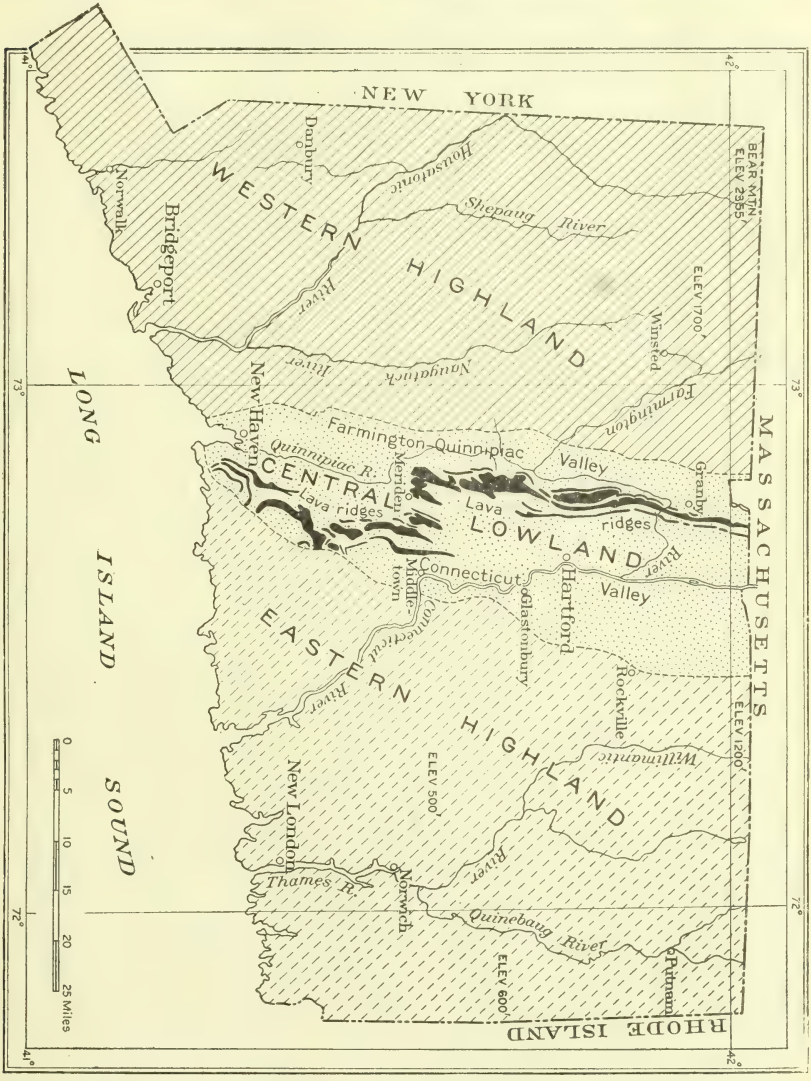


FIGURE 1.—Map of Connecticut, showing physiographic provinces.

which "present, when viewed from an elevated point on their surface, the appearance of a general level, with a rolling or undulating outline, over which the view often extends to a very great distance, interrupted only by isolated summits or ridges, usually of small ex-

[a] Percival, J. G., Report on the geology of Connecticut, 1842, p. 477.

tent." A good view from any exposed point in the highlands confirms this impression of a plateau surface rather than a confused mingling of hills. As concisely stated by Professor Rice:[a] "If we should imagine a sheet of pasteboard resting upon the summits of the highest elevations of Litchfield County and sloping southeastward in an inclined plane, that imaginary sheet of pasteboard would rest on nearly all the summits of both the eastern and the western highlands." Certain mountains project above the general level of the plateau and many valleys are cut below it. Owing to the resistant character of the rocks composing them, Great Hill, Cobalt, 700 feet; Lantern Hill, Mystic, 520 feet; Mount Horr, Canton, 880 feet; Mount Prospect, Litchfield, 1,365 feet; Mount Haystack, Norfolk, 1,680 feet; and other points stand out as prominent landmarks above the general surface at their base.

The origin of the highland plateau is revealed by an examination of the composition and structure of its basement rock, which clearly shows that the surface as it now exists is not the result of accumulation of sediments of great thickness. The bed rock of the highlands is not sedimentary nor horizontal, but is metamorphic and igneous rock which has been folded and twisted and injected, and which could have been formed only at a great depth below the earth's surface. Mountains have been removed from western and eastern Connecticut, and the remaining rocks, with their bewildering complexity of structure, are but the stumps of old land masses which have been sawed horizontally across by the agents of erosion. If the present valleys were filled and a few projecting hills cut down the conditions of Cretaceous time would be restored and the highlands would appear as a plain—the result of long-continued, ceaseless activity on the part of rain, frost, and streams.

Eastern highland.—The counterpart of the western highland is found in the eastern part of the State, but the eastern highland represents much less contrast in relief and does not attain such altitudes. Practically all the prominent hills and ridges in this province are under 700 feet in height, and only in the towns along the Massachusetts line is an elevation of 1,000 feet attained, the culminating points being Rattlesnake Hill, Somers, 1,080 feet; Bald Mountain, Somers, 1,120 feet; Soapstone Mountain, Somers, 1,061 feet; Hedgehog Hill, Stafford, 1,180 feet; Bald Hill, Union, 1,286 feet; Stickney Hill, Union, 1,220 feet; Lead Mine Hill, Union, 1,140 feet; Snow Hill, Ashford, 1,213 feet; and Hatchet Hill, Woodstock, 1,040 feet.

Valleys in the highlands.—The valleys in the highlands are those which have been cut since the formation of the peneplain (see p. 33), and their character is determined by the rocks which they traverse and by the age and size of the streams which have occupied them.

[a] Rice, W. N., and Gregory, H. E., Manual of Connecticut geology, 1906, p. 20.

The western highland is traversed by two well-marked valleys—those of Housatonic-Norwalk and Naugatuck-Still rivers, which inclose a rectangle of the highest land within the State. These valleys are intrenched 400 to 600 feet in the plateau and, although not occupied by continuous streams, they constitute the only feasible lines of communication between the northern and southern parts of the western highland. The two valleys are connected by the gorgelike trough of the Housatonic, which cuts through the rock ridges with a fall of 10 feet per mile. The Housatonic Valley at Danbury and at Canaan and the Naugatuck-Still Valley at Winsted widen into undulating plains. The Farmington Valley through the highlands is a gorge less than 1,000 feet in width below Riverton, and still narrower at Hartland, where it is sunk 600 feet below the plateau, and at Satans Kingdom it is barely 200 feet wide. Nearly all the minor streams of the western highland are intrenched in fairly narrow valleys, except the Pomperaug, which meanders freely over a miniature lowland on Triassic sediments.

In the eastern highland the valleys entering the lowland are mostly short and narrow and of high gradient. One important valley gorge, now occupied by Connecticut River, leads from the central lowland southeastward to the Sound. The Thames Valley is a fiord to Norwich. Its eastern branch, the Quinnebaug, is a steep-walled valley to South Canterbury, above which it widens into a plain through Plainfield, Killingly, and Putnam. The Shetucket-Willimantic Valley is broad and open through most of its course, as are also its northern branches, which divide the highland into segments.

The floor of the highland valleys is bed rock, till, or stratified drift, no stream having entirely removed the cover of glacial drift along its path. Some streams, in fact, like the east branch of the Farmington, flow through almost their entire courses without reaching bed rock.

A glance at the topographic map shows that the chief valleys trend either north and south or northwest and southeast. For example, the Housatonic from Gaylordsville to Derby, the Connecticut from Middletown to Lyme, the Farmington from Colebrook to Farmington, and the Shetucket and many valleys of lesser size are alike in their north-south alignment. The upper Connecticut, the Willimantic, the Mount Hope, Little River (Windham County), and several minor streams trend in a common direction. There is nothing in the nature of the rock which accounts for the common alignment of these two groups of valleys and, if only present geologic conditions are taken into account, the southeasterly courses of the Housatonic below New Milford and of the Connecticut below Middletown are anomalous, for these rivers leave well-developed valleys of limestone and sandstone and cut their way through the most resistant gneisses and schists. There seems no escape from the conclusion that they

established their courses on an ancient coastal plain which sloped to the southeast. As a result of the uplift and consequent erosion, the strata forming the plain have been removed, but the streams have maintained their original directions, cutting valleys deep into the rocks of the plateau. (See p. 19.)

It has been shown by Hobbs[a] that the main valley lines of the State coincide in direction with five prominent systems of joints and faults and there is doubtless some genetic relationship between the joints and the trend of trough lines.

CENTRAL LOWLAND.

Extent and character.—The central lowland differs from the highlands in altitude, character of bed rock, drainage, and types of hills and valleys. In extent it is coincident with the larger of the two areas of Triassic sediments within the State. Except in the lava ridges, the altitude of the lowland averages about 100 feet and only in the region south of Middletown does it exceed 500 feet. As viewed from the highlands—for instance, at Bald Mountain, Somers, or Box Mountain, Bolton, from Bristol, or from the ridges near Canton—the lowland surface appears as a plain from which rise ridges of lava. The edges of the highland areas, as viewed from the lowland, present abrupt walls, as seen in Southington and Somers, or steeply rising slopes. In Glastonbury, Middletown, and Branford the lowland merges imperceptibly into the highland.

Lava ridges.—The most marked topographic feature of the lowland and, in fact, of the entire State, is the series of basalt ridges which extend from North Granby to East Haven. As far south as Meriden the ridges form a continuous line of elevation broken only by gaps and passes. From the Hanging Hills this ridge line passes by a series of rough steps to Beseck Mountain and thence continues southward as Totoket and Saltonstall ridges.

The most prominent parts of this ridge system are Peak Mountain, 665 feet; Talcott Range, the highest point of which is 960 feet; Rattlesnake Mountain, 750 feet; Ragged Mountain, 754 feet; Hanging Hills, 700 to 1,000 feet; Lamentation Mountains, 654 and 725 feet; Higby Mountain, 920 feet; Beseck Mountain, 840 feet; Pistapaug Mountain, 640 feet; Totoket Mountain, 780 feet; Saltonstall Ridge, 240–245 feet. The culminating point is West Peak, Meriden, 1,007 feet, which is fully up to the level of the highlands and furnishes a magnificent view of the Farmington-Quinnipiac Valley and the Wolcott Plateau beyond. The ridge of lava faces westward as a bold escarpment, but slopes gently to the east, where it merges into the lowland floor. Breaks through the ridge formed by streams or by faults furnish passes for railroads at Tariffville, New Britain, Meriden, and Baileyville.

[a] Hobbs, W. H., River system of Connecticut: Jour. Geology, vol. 9, 1901, pp. 469–485.

Farmington and Connecticut valley lowlands.—The central ridge of lava forms a conspicuous and effective line of demarkation between the two parts of the central lowland—the Connecticut Valley and the Farmington-Quinnipiac Valley.

The Connecticut Valley area from Thompsonville to Middletown is practically a plain of drift and till 5 to 10 miles in width and with differences in elevation of less than 200 feet. South and west of Middletown the valley area passes by gradual stages into the eastern highland and the central ridges. The elevations in the Connecticut Valley lowland are drumlins and other glacial deposits and till-covered sandstone knolls. The streams tributary to the Connecticut are ditches cut into glacial deposits. The Scantic, Podunk, Hockanum, and others seldom reveal rock floor; Stony Brook (Suffield) is the type of a few streams which have cut through the drift to the sandstone below.

The Farmington-Quinnipiac Valley extends from New Haven northward across the State and is bounded on the west by the steep edge of the western highland and on the east by the broken wall of the central ridge. It is occupied by three rivers—the Farmington, Quinnipiac, and Mill (New Haven)—all of which, in common with their tributaries, flow almost entirely on glacial drift. From the floor of the Farmington-Quinnipiac Valley rise a number of trap hills which break the continuity of the plain. The most prominent of these are the Barndoor Hills, 600 to 700 feet; Mount Carmel, 737 feet; West Rock, 405 feet; and East Rock, 359 feet. The level, drift-filled floor of this valley lowland, together with the slight difference in elevation between New Haven and the Congamuck ponds, made the valley an attractive route for a canal, which was built in 1829 and was later succeeded by the Northampton Railroad.

COAST LINE.

The coast line is much indented and presents a multitude of bays, headlands, points, inlets, and marshes. Rock islands occur in groups, as at Norwalk and off Branford, or are scattered irregularly along the shore. Westward-moving tides and currents have built innumerable beaches, bars, and spits along the coast, thus greatly modifying its original outline. The character of the coast is due to the fact that the land has been depressed, allowing the sea water to enter the old valley now constituting Long Island Sound and to drown the irregular southern edge of the denuded peneplain.

DRAINAGE.

Connecticut is drained largely by streams which rise within its borders. Only two streams of large size—the Connecticut and the Housatonic—carry water from lands beyond the State, and the

Massachusetts section of the Housatonic serves but a small area. The three main river systems are the Housatonic, the Connecticut, and the Thames, which drain, respectively, 1,272, 1,443, and 1,164 square miles, or altogether 78 per cent of the surface.

Of the streams which enter Long Island Sound independently—the Byram, Mianus, Mill (Stamford), Norwalk, Saugatuck, Mill (Fairfield), Poquonock, Wopowaug, West, Mill (New Haven), Quinnipiac, Hammonassett, Niantic, Mystic, Pawcatuck, and certain smaller ones—the Quinnipiac, 35 miles long, is the only one over 20 miles in length, and all have small drainage basins.

In a number of places the divides between adjoining drainage areas are ill defined and a few stream systems coalesce. Thus the limestone valley extending from New Preston to Bedford, N. Y., an area of slight relief, is drained by five streams that have independent outlets to the sea—the Mianus, Norwalk, Saugatuck, Housatonic, and the Croton (a tributary to the Hudson). Likewise the Quinebaug, Bigelow Brook, the Natchaug, and the Shetucket together form a closed ring of water surrounding ten towns in the northeastern part of the State.

The lower ends of the streams entering the Sound are drowned, and the tides, 4 to 7 feet in height, reach up these streams to a greater or less distance. For example, the Connecticut is tidal to Hartford, 44 miles; the Thames to Norwich, 15 miles; the Housatonic to Derby, 11 miles; the Quinnipiac to Quinnipiac, 10 miles. Accordingly the lower reaches of the streams along the coast line are of no value for water supplies.

The streams of the highlands have steep gradients and their flow is interrupted by numerous waterfalls and rapids. This is particularly true of the streams entering the central lowland and of small streams in general. Thus, the Farmington from Cold Spring, Mass., to New Hartford falls 29.76 feet to the mile; the Shepaug descends at the rate of 30.5 feet to the mile, making one drop, at Bantam, of 108 feet in less than three-quarters of a mile; Moodus River falls 350 feet in 2 miles. Even the Housatonic falls 3.5 feet to the mile from Stratford to Shepaug; 10.2 feet to the mile from Shepaug to a station 1.8 miles above Cornwall bridge; 19.4 feet to the mile from this last-named point to Falls Village; and 9.2 feet to the mile from Falls Village to Ashley Falls, one-half mile north of the Connecticut boundary line. The descent of the Housatonic is accomplished by stretches of gravelly rapids alternating with reaches of relatively quiet water, but at New Milford, Bulls Bridge, and Falls Village there is an abrupt drop over rock ledges. At Falls Village the combined height of the falls is about 100 feet.[a]

[a] Porter, Dwight, Report on water power of the region tributary to Long Island Sound: Tenth Census, vol. 16, 1885.

The streams of the lowland area have slight fall and in some places are aggrading their valleys. The Scantic, Hockanum, Farmington, Pequabuck, Mill (New Haven), Farm, and others are sluggish streams which meander freely. The Quinnipiac, with a drainage basin of 156 square miles and a length of 35 miles, falls 5 feet to the mile from Plantsville to New Haven. The Connecticut has a fall of only 0.6 foot to the mile from Enfield Rapids to Hartford; and from Hartford to Saybrook no fall whatever. The entire fall of Connecticut River in crossing the State in the lowlands is about 30 feet, as compared with the fall of Housatonic and Willimantic-Shetucket-Thames rivers in the highlands—650 and 600 feet, respectively. There are, however, many waterfalls and rapids of considerable size and great picturesqueness along the streams of the central lowland.

Lakes, swamps, and salt marshes occupy 145 square miles of the State, the topographic map showing 1,026 lakes, the largest of which is Lake Bantam, with an area of 1.56 square miles, or 999 acres. Swamps are even more abundant than lakes, and if the smaller, partly drained ones are taken into account they number several thousand. The importance of these water bodies is evident. They furnish supplies for cities, add greatly to the beauty of the landscape, and are particularly effective in controlling the drainage, serving as reservoirs to retard the escape of rainfall and thus preventing destructive floods.

A glance at the map of Connecticut will show that the drainage is to the southeast and that the streams flow in accord with the general slope of the plateau, but even a superficial glance reveals the fact that not all the larger streams are in the prominent valleys and that many occupy positions where the bed rock is unfavorable for valley development. The Connecticut, for instance, instead of following the sandstone to New Haven, leaves the lowland at Middletown and turns abruptly into the crystalline rocks of the highlands, through which it has cut a deep gorge. Likewise the Housatonic, which follows a limestone valley down to Still River, turns southeastward across rugged crystalline rocks instead of continuing in the valley indicated by rock structure. The same is true of a number of smaller streams. Anomalies of another class are illustrated in the arrangement of certain smaller streams whose direction and grade, as well as character of valley, are entirely out of accord with the present topography. For example, Still River at New Milford and a stream of the same name at Winsted flow in a direction contrary to the slope of their valleys and enter their master streams by dropping over falls. The Farmington follows the slope of the ancient peneplain from Colebrook River to Farmington, there turns northward, cuts through a trap ridge at Tariffville, and finally reaches the Sound after flowing a dis-

tance of 103 miles instead of the necessary 64 miles to New Haven or 74 miles by way of the Connecticut at Middletown.

Without going further into detail, it may be stated that the characteristic features of the present drainage are due to two main causes. First, the streams were established on a peneplain during Cretaceous time and followed the slope to the south and southeast regardless of the character of the underlying rocks. The Connecticut, Housatonic, and other streams have maintained this inherited position. Second, the entire drainage of the State has been modified by glaciation. The courses of some streams have been reversed, other streams have been cut in two, and still others have been entirely obliterated or are represented by lakes and swamps. In fact a widespread rearrangement of streams as to direction and grade has been brought about.

FORESTS.

The distribution of forests in the State follows closely the subdivisions into highland and lowland areas. The eastern and western highlands are largely forest covered, and in recent years the forest areas have been encroaching on the agricultural districts. In the central lowland the soil, transportation facilities, and nearness to market render agriculture more remunerative, and the forests are represented by small, scattered wood lots. Taken as a whole, Connecticut is a well-timbered country, 39 per cent of its area being covered with trees.

CLIMATE.

METEOROLOGICAL DATA.[a]

Sixteen climatological stations are maintained by the United States Weather Bureau in Connecticut—at Bridgeport, Canton, Colchester, Cream Hill, Danielson, Hartford, Hawleyville, New Haven, New London, North Grosvenordale, Norwalk, Southington, Storrs, Torrington, Voluntown, and Waterbury. In Falls Village, Middletown, South Manchester, Wallingford, and West Simsbury record is kept of rainfall and temperature.

The following tables and figures 2, 3, and 4 present data collected at three selected stations; one in the eastern highland—Storrs, at an elevation of 640 feet; one in the central lowland—New Haven, elevation 25 feet; and the third in the western highland—Cream Hill, elevation 1,300 feet. The tables for the New Haven station give records of rainfall, temperature, humidity, and wind velocity, which are controlling factors in ground-water supply.

[a] From United States Weather Bureau records.

Precipitation (in inches) at Storrs, 1897–1906.

[Elevation, 640 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	3.84	3.40	3.66	2.37	4.44	2.79	12.24	5.23	1.39	0.92	7.14	5.61	53.03
1898	4.70	4.03	3.00	4.44	3.81	2.48	6.24	5.87	2.22	6.18	6.11	1.96	51.13
1899	3.70	3.97	6.30	2.20	1.27	3.72	5.55	3.27	3.31	1.54	2.10	2.14	39.13
1900	3.42	7.31	6.73	2.67	4.91	4.32	2.76	2.03	2.27	3.00	6.79	2.22	48.43
1901	2.17	1.05	7.18	9.51	6.30	1.96	5.54	7.58	4.33	1.97	3.04	9.55	60.18
1902	2.53	5.11	6.35	3.88	1.59	3.24	7.48	2.17	7.05	5.68	1.10	5.86	53.75
1903	3.79	5.18	7.09	2.81	.50	9.24	4.56	4.52	1.81	2.79	1.95	4.27	48.51
1904	4.55	2.80	3.31	6.40	1.96	2.53	1.85	6.00	4.71	2.19	1.47	2.42	40.19
1905	3.57	1.21	3.45	2.87	.90	4.53	1.77	2.63	5.79	2.57	2.73	4.12	36.14
1906	3.16	2.68	5.46	4.40	5.87	2.18	5.03	2.16	2.05	4.85	2.39	2.80	43.63
Mean	3.54	3.67	5.25	4.16	3.15	3.70	5.30	4.15	3.49	3.17	3.48	4.10	47.16

	Winter.	Spring.	Summer.	Fall.
Mean for season	11.31	12.56	13.15	10.14

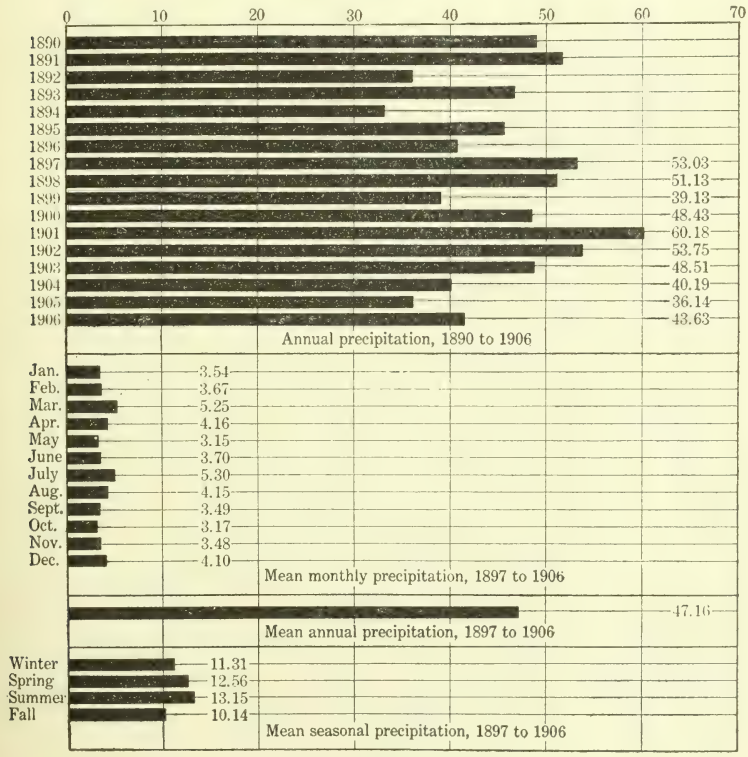


FIGURE 2.—Diagram showing precipitation, in inches, at Storrs.

Precipitation (in inches) at New Haven, 1897–1906.

[Elevation, 25 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	3.85	2.00	3.66	2.44	5.03	2.47	10.63	6.81	2.42	1.25	5.72	5.61	57.80
1898	4.90	4.55	2.54	4.43	8.03	.21	5.03	6.65	2.30	7.22	5.69	2.11	53.66
1899	4.33	3.39	7.28	1.79	5.52	2.59	4.17	.65	3.33	1.78	1.89	1.56	35.28
1900	3.00	6.39	4.21	1.95	3.30	1.79	2.28	.90	2.10	2.03	4.14	2.14	34.83
1901	1.38	.54	5.80	9.03	6.38	.25	4.40	6.92	5.70	2.95	1.61	7.65	68.81
1902	1.83	3.58	4.63	3.40	1.61	4.35	3.26	2.14	5.84	6.41	.79	6.49	44.33
1903	3.17	3.98	5.09	2.61	.31	7.41	2.17	6.96	2.20	2.94	1.85	2.53	41.22
1904	2.78	2.52	3.28	6.64	2.94	2.46	2.08	6.27	4.96	2.21	1.95	3.64	41.73
1905	4.14	2.06	2.96	3.42	1.18	5.87	2.86	7.20	5.07	2.21	1.53	4.83	43.33
1906	3.20	2.45	5.67	4.48	4.75	5.14	5.62	1.13	4.82	7.44	2.42	4.18	51.30
Mean	3.32	3.15	4.51	4.02	3.91	3.25	4.25	4.56	3.87	3.64	2.76	4.07	45.31

	Winter.	Spring.	Summer.	Fall.
Mean for season	10.54	12.44	12.06	10.27

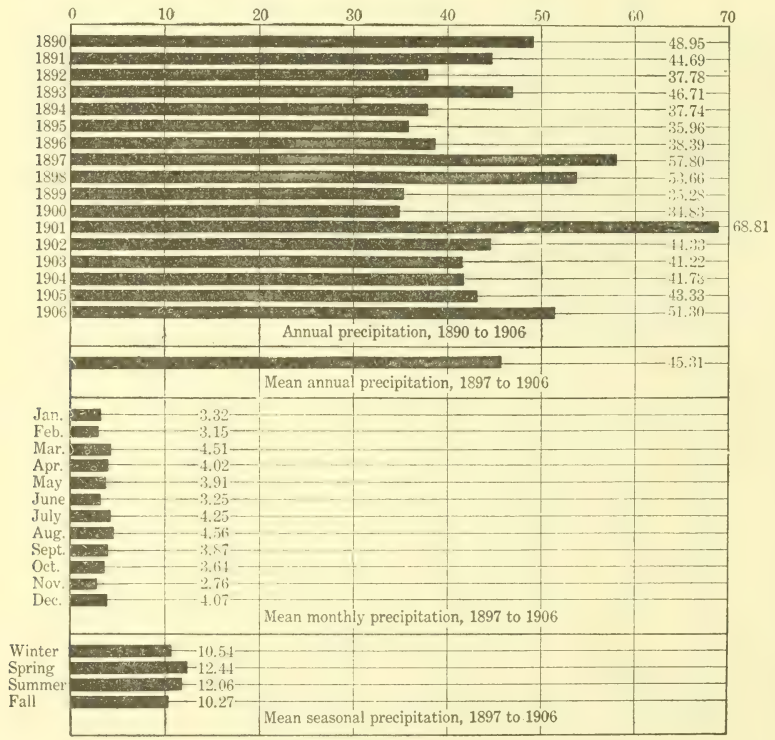


FIGURE 3.—Diagram showing precipitation, in inches, at New Haven.

The average precipitation at New Haven for thirty years ending December 31, 1903, was as follows:

Average precipitation at New Haven for thirty years ending December 31, 1903.

	Inches.
January	4.03
February	4.02
March	4.51
April	3.45
May	3.71
June	2.97
July	5.01
August	4.81
September	3.66
October	4.28
November	3.73
December	3.79
Annual	47.97
Mean for season:	
Winter	11.84
Spring	11.67
Summer	12.79
Fall	11.67

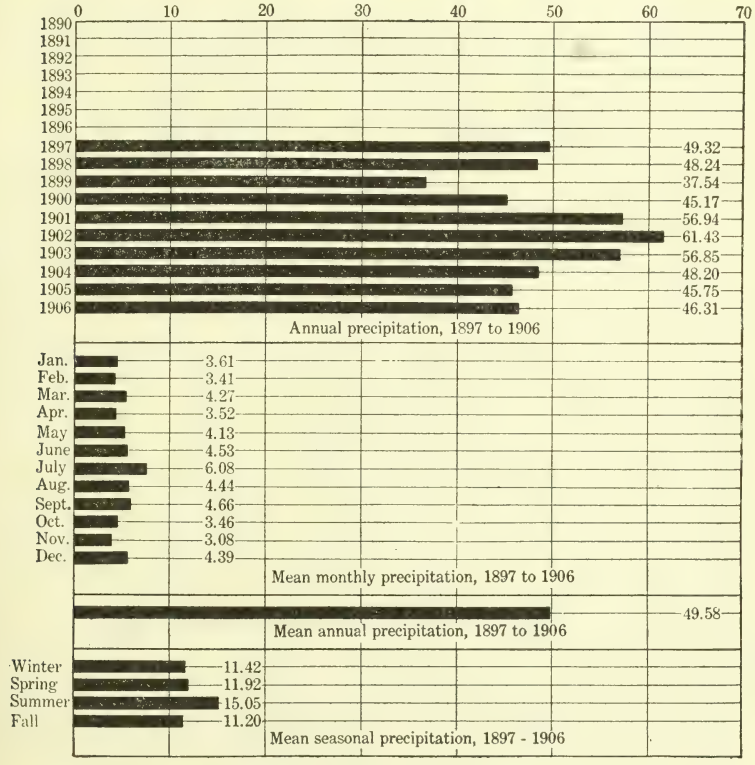


FIGURE 4.—Diagram showing precipitation, in inches, at Cream Hill.

Precipitation (in inches) at Cream Hill, 1897–1906.

[Elevation, 1,300 feet.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	3.54	2.21	2.09	3.16	4.22	5.15	9.71	5.28	2.85	1.04	5.54	4.53	49.32
1898	3.52	3.68	2.37	4.31	6.70	2.87	1.79	6.77	4.25	3.35	6.46	2.17	48.24
1899	3.47	4.13	5.84	1.47	1.75	3.39	6.70	1.11	4.21	1.67	1.59	2.21	37.54
1900	2.82	5.97	3.84	1.95	5.13	4.42	6.09	2.18	1.75	2.73	5.29	3.00	45.17
1901	1.52	.84	7.33	6.83	6.90	1.69	4.57	6.97	4.52	4.37	3.26	8.14	56.94
1902	3.26	4.90	4.68	4.76	2.99	5.06	9.40	4.70	7.83	5.42	.75	7.68	61.43
1903	3.93	4.97	4.94	3.20	1.39	9.74	4.07	5.65	2.85	6.39	3.10	6.65	56.85
1904	4.69	3.13	4.46	3.12	4.28	3.52	6.15	3.89	7.90	2.71	1.24	3.09	48.20
1905	6.91	1.68	3.12	2.74	2.35	3.90	5.83	4.71	6.83	2.90	2.19	2.59	45.75
1906	2.41	2.55	4.06	3.67	5.61	5.60	6.47	3.14	3.58	4.02	1.36	3.84	46.31
Mean	3.61	3.41	4.27	3.52	4.13	4.53	6.08	4.44	4.66	3.46	3.08	4.39	49.58

	Winter.	Spring.	Summer.	Fall.
Mean for season	11.41	11.92	15.05	11.20

The average precipitation recorded at ten stations in Connecticut for the years 1893–1903 is as follows:

Average precipitation at ten stations in Connecticut, 1893–1903.

	Inches.
January	4.28
February	3.94
March	4.23
April	3.53
May	4.03
June	2.95
July	4.42
August	4.30
September	3.34
October	4.04
November	4.48
December	3.44
Annual	46.98
Mean for season:	
Winter	11.66
Spring	11.79
Summer	11.67
Fall	11.86

Monthly and annual temperature (°F.) at Storrs, 1893–1903.

[Elevation, 640 feet.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean	24	24	36	46	56	64	69	68	61	50	38	30	47
Highest monthly mean	28	28	43	48	60	68	72	70	64	54	44	33	.....
Lowest monthly mean	17	19	29	42	54	59	65	62	56	45	34	23	.....

	Winter.	Spring.	Summer.	Fall.
Mean for season	26	46	67	50

Monthly and annual temperature (°F.) at New Haven, 1873–1903.

[Elevation, 25 feet.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean	28	29	35	46	58	66	72	70	64	53	41	32	50
Highest monthly mean	37	36	45	52	64	71	76	73	70	58	47	39	.....
Lowest monthly mean	20	20	27	39	51	61	68	65	59	48	34	26	.....

	Winter.	Spring.	Summer.	Fall.
Mean for season	30	46	69	53

For thirty-one years the highest temperature at New Haven was 100°, in September, 1881, and the lowest was 14° below zero, in January, 1873.

Monthly and annual temperature (°F.) at Cream Hill, 1897–1907.

[Elevation, 1,300 feet.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean	23.1	22.0	32.9	44.0	56.0	64.0	69.4	66.6	61.4	51.0	36.7	26.0	46
Highest monthly mean	30.2	26.6	39.2	45.4	59.0	66.0	72.1	70.6	64.6	54.6	42.4	29.7	.....
Lowest monthly mean	17.3	16.3	26.0	40.6	53.8	60.0	66.1	61.2	58.6	47.6	32.2	21.4	.....

	Winter.	Spring.	Summer.	Fall.
Mean for season	23.7	43.3	66.7	49.7

Mean relative humidity (per cent) at New Haven, 1901–1906.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1901	72	62	74	77	79	70	80	83	80	76	67	77	75
1902	70	69	76	69	65	71	77	75	84	78	79	72	74
1903	71	73	78	65	65	82	73	79	79	79	68	69	73
1904	72	67	72	70	69	75	75	77	80	68	72	70	72
1905	68	63	71	66	71	74	76	81	80	71	67	70	72
1906	74	69	69	63	70	75	82	81	77	76	67	72	73
Mean	71	67	73	68	70	75	77	79	80	75	70	71	73

	Winter.	Spring.	Summer.	Fall.
Mean for season	70	70	77	75

Mean relative humidity (per cent) at New Haven for fifteen years ending in 1903.

Time.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
8 a. m	74	73	71	74	77	78	80	80	78	76	75	76	76
8 p. m	71	72	69	74	76	78	78	80	76	74	72	72	74

Average velocity (miles per hour) and direction of wind at New Haven, 1900–1905.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1900—Vel.	10.1	11.3	10.6	9.5	9.1	8.8	8.1	7.1	8.1	9.0	10.7	8.9	9.3
Dir.	N.	W.	N.	N.	SW.	SW.	SW.	SW.	SW.	N.	N.	SW.	S.W
1901—Vel.	9.9	11.2	11.0	13.3	9.8	7.8	6.8	6.9	7.1	8.6	10.2	10.4	9.4
Dir.	N.	NW.	NW.	NE.	S.	S.	SW.	S.	SW.	N.	NW.	N.	N.
1902—Vel.	9.8	13.0	11.4	9.9	9.2	8.4	7.2	7.2	8.4	8.2	9.4	10.8	9.4
Dir.	NW.	W.	N.	S.	SW.	SW.	SW.	NW.	N.	N	N.	N.	N.
1903—Vel.	10.2	10.0	9.5	11.7	8.0	8.5	7.8	7.3	7.9	11.3	8.4	10.9	9.3
Dir.	N.	W.	NE.	N.	S.	NE.	SW.	N.	SW.	N.	N.	W.	N.
1904—Vel.	10.3	10.6	10.1	10.7	8.2	8.2	8.2	7.7	8.3	9.5	9.0	10.7	9.3
Dir.	N.	N.	NW.	NW.	S.	S.	S.	S.	N.	N.	NW.	N.	N.
1905—Vel.	11.2	10.7	8.2	10.1	9.0	7.8	7.8	7.9	8.3	8.6	9.8	9.7	9.1
Dir.	N.	W.	N.	NW.	S.	S.	S.	SW.	N.	N.	NW.	SW.	N.
Mean—Vel.	10.3	11.1	10.1	10.9	8.9	8.3	7.7	7.4	8.0	9.2	9.6	10.2	9.3
Dir.	N.	W.	N.	N. NW.	S.	S.	SW.	S. SW.	N. SW.	N.	N. NW.	N.	N.

	Winter.	Spring.	Summer.	Fall.
Mean for season—Vel.	10.5	10.0	7.8	8.9
Dir.	N.	N.	S. SW.	N.

Prevailing winds at New Haven for thirty-one years.

January	North.	August	South.
February	North.	September	Southwest.
March	Northwest.	October	North.
April	Northwest.	November	North.
May	South.	December	North.
June	South.	Annual	North.
July	South.		

SUMMARY.

The foregoing tables indicate that the climate of Connecticut possesses both continental and oceanic features directly related to the highlands and to Long Island Sound. The winters are long and severe; the summers are short, beginning abruptly in June and passing gradually into winter through autumn. Areas of high and low barometer which affect the weather of the State pass to the north down the St. Lawrence Valley, along the coast or directly across the State. Precipitation is uniformly abundant, and excessively dry years are unknown. There has been little change in the annual amount of rain for one hundred years, and the variation in seasonal amount is slight. (See figs. 2 to 4.) In fact, Connecticut may well serve as a type of uniform, evenly distributed rainfall of ample amount, in contrast with regions of seasonal rains and great annual variation.

The relation of temperature to ground-water problems is shown by the fact that percolation through sand is nearly twice as rapid at 100° F. as at 50°, and, accordingly, the amount of rainfall absorbed by the ground is subject to large monthly and seasonal variation. The proportion of the total precipitation found in the ground at each month in the year is given in the following table:[a]

Humidity of the ground.

Month.	Per cent at—			Month.	Per cent at—		
	1 foot.	2 feet.	3 feet.		1 foot.	2 feet.	3 feet.
January	89	95	98	July	20	15	10
February	76	82	88	August	32	28	22
March	66	72	77	September	34	40	34
April	54	57	65	October	57	52	48
May	44	45	48	November	66	64	67
June	32	30	30	December	82	74	83

SURFACE WATER SUPPLY.

SOURCE AND CHARACTER.

Of the water which falls as rain, a part is evaporated, another part enters the ground, and a third part goes directly into streams and is thus carried to the sea. The amount of water which is carried by streams has been approximately determined (see tables below), but there are no records of the amount evaporated, and accordingly the proportion of the rainfall absorbed by rocks and soils, and therefore available for springs and wells, is unknown. However, the amount evaporated is certainly small and, for rough calculations, the total rainfall may be divided into that which enters the ground (ground water) and that which is carried in streams (run-off).

The relation of rainfall to run-off can not be stated definitely, because several factors of unknown value are included. The rate of precipitation, the topography of the surface, the texture of the soil, and the structure of the rocks are all to be considered. The presence of lakes and swamps along the stream's course and on its catchment area modify the surface run-off, and a large but unknown amount of ground water enters streams and lakes without reaching the surface. For instance, Lake Saltonstall has a small drainage area—4 square miles—and should receive 4,000,000 gallons of water a day. It actually receives, however, a much larger amount than can be accounted for by ordinary surface drainage and is presumably fed by subterranean springs and ground-water seepage.

The presence of forests affects the relation of rainfall to run-off by increasing and regulating the flow of ground water. Deforestation

[a] Sherman, Connecticut Almanac, 1885, p. 39.

promotes evaporation, increases the run-off, and tends to produce seasons of flood.

The general run-off of streams in the eastern part of the United States is 0.05 to 0.5 cubic foot per square mile per second, and streams tributary to Long Island Sound carry 17½ to 27½ inches of rainfall out of an annual total of 40 to 52 inches.[a] Variation in annual run-off is indicated by the record of Connecticut River, which shows the ratio of the run-off for a dry year to be 94 per cent of an average year's flow.

QUANTITY AVAILABLE.

The rivers whose discharge and run-off records are given below were chosen as typical Connecticut streams and fairly represent prevailing conditions. The Shetucket is a stream of the eastern highland, established on gneiss and schist. The Connecticut drains the sandstone lowland, and the Housatonic flows for a large part of its course above Gaylordsville in a limestone valley. The run-off record is compared with the rainfall record of the meteorological station nearest the point where the discharge is measured.

Discharge and run-off of Shetucket River at Willimantic April 4, 1904, to January 1, 1907.

Date.	Discharge (second-feet).			Run-off.			Rainfall at Storrs (inches).
	Maximum.	Minimum.	Mean.	Per square mile (second-feet).	Depth (inches).	Relation to rainfall (per cent).	
1904.							
April 4	4,420	758	1,784	4.50	4.51	70.4	6.40
May	2,350	385	920	2.32	2.68	136.7	1.96
June	555	84	326	.823	.918	36.3	2.53
July	345	84	221	.558	.643	34.8	1.85
August	930	126	373	.942	1.09	18.1	6.00
September	2,930	66	428	1.08	1.20	25.5	4.71
October	930	207	396	1.00	1.15	52.5	2.19
November	990	150	381	.962	1.07	72.8	1.47
December 1–17, 28–31	3,755	126	831	2.10	1.64	67.7	2.42
1905.							
March	3,865	275	1,937	4.89	5.64	163.5	3.45
April	4,195	510	1,254	3.17	3.54	124.0	2.87
May	706	275	455	1.15	1.33	147.8	.90
June	1,560	66	565	1.43	1.60	35.3	4.53
November	555	207	364	.919	1.03	37.7	2.73
December	2,930	555	902	2.28	2.63	63.8	4.12

[a] Porter, Census for 1880, vol. 16, pt. 1.

Discharge and run-off of Connecticut River at Hartford January 1, 1871, to January 1, 1886.

[Drainage area, 10,234 square miles.]

Date.	Discharge.			Run-off.			Rainfall (inches).
	Maximum.	Minimum.	Mean.	Per square mile (second-feet).	Depth (inches).	Relation to rainfall (per cent).	
1871	87,460	5,520	17,433	1.70	21.11	56.2	37.70
1872	98,100	6,250	19,335	1.89	26.71	56.6	46.71
1873	109,800	5,390	23,061	2.25	30.62	69.9	43.85
1874	134,000	5,210	23,340	2.28	30.81	71.4	43.24
1875	90,100	5,700	18,114	1.77	23.95	55.6	43.07
1876	120,800	5,360	22,080	2.15	29.15	60.6	48.18
1877	128,200	5,700	16,683	1.63	22.09	51.5	42.92
1878	89,350	5,350	20,766	2.02	27.51	54.7	50.20
1879	116,400	5,550	18,852	1.84	24.91	52.6	47.24
1880	65,550	5,200	13,720	1.34	18.25	45.6	40.02
1881	74,000	5,250	18,026	1.76	23.88	51.0	46.93
1884	74,700	5,150	19,861	1.94	23.65	60.4	45.15
Period	134,000	5,150	19,157	1.87	25.10	57.0	44.53
1885.							
January	65,550	17,000	34,661	3.38	3.89	93.9	4.14
February	23,200	10,500	14,711	1.44	1.50	51.4	2.92
March	16,400	7,600	11,706	1.14	1.32	89.6	1.47
April	88,600	13,100	26,250	2.56	2.86	102.4	2.79
May	63,700	10,250	25,869	2.52	2.91	119.7	2.43
June	27,900	5,800	10,785	1.06	1.28	40.0	3.20
July	10,500	6,000	7,909	.77	.89	25.0	3.56
August	18,000	5,300	9,148	.89	1.03	12.8	8.06
September	13,100	6,000	8,105	.79	.88	47.8	1.84
October	21,350	6,750	10,084	.98	1.13	24.0	4.72
November	78,200	12,400	33,067	3.23	3.60	69.3	5.20
December	35,400	10,000	21,005	2.05	2.36	72.0	3.29
Year	88,600	5,300	17,775	1.73	23.65	54.3	43.62

Discharge and run-off of Housatonic River at Gaylordsville, 1901–1903 and 1906.

[Drainage area, 1,020 square miles.]

Date.	Discharge (second-feet).			Run-off.			Rainfall (inches).
	Maximum.	Minimum.	Mean.	Per square mile (second-feet).	Depth (inches).	Relation to rainfall (per cent).	
1901	14,300	303	2,216		29.65	52.1	56.94
1902	31,000	525	2,920	2.861	38.62	62.9	61.43
1903	25,700	550	3,006	2.946	39.65	69.8	56.85
1906.							
January	3,170	938	1,800	1.76	2.03	84.2	2.41
February	4,630	788	1,630	1.60	1.67	65.5	2.55
March	10,000	1,130	2,910	2.85	3.29	81.0	4.06
April	8,930	2,460	4,780	4.69	5.23	142.5	3.67
May	5,060	1,090	2,110	2.07	2.39	42.6	5.61
June	2,370	928	1,630	1.60	1.78	31.8	5.60
July	2,120	421	984	.965	1.11	17.2	6.47
August	1,310	347	818	.802	.92	29.3	3.14
September	876	296	554	.543	.61	17.0	3.58
October	2,220	296	861	.844	.97	24.1	4.02
November	1,980	550	992	.973	1.09	80.1	1.36
December	1,440	686	958	.939	1.08	28.1	3.84
The year	10,000	296	1,670	1.64	22.17	47.9	46.31

POPULATION AND INDUSTRIES.

The physiographic division of Connecticut into highland and lowland areas has been a controlling factor in determining the settlement and character of life of the people of the State. The bulk of the population at the present time is grouped in three areas:

First, the central lowland, containing the towns of New Haven, Hartford, Middletown, New Britain, Meriden, etc., in which 39 per cent of the entire population of the State is located. This region was first settled in 1637 and the population has increased gradually from that date. The favorable conditions of the lowland area are the fertile soil, which is readily tilled, and the ease of establishing lines of communication by wagon roads, canals, and railroads.

Second, on the shores of Long Island Sound, where are located Norwalk, Stamford, Bridgeport, New London, and other towns, which together have a population of 199,719, or 22 per cent of the total.

Third, in the highland valleys, where Waterbury, Winsted, Willimantic, and many smaller towns are located and where 26 per cent of the population reside. The original attractions of these places were the water power and ease of communication along valleys. Collinsville is typical of many small villages that have been built up about a factory whose location was determined by excellent water power.

The towns of the State outside of these three groups have attracted but 13 per cent of the population. The soil is thin but of fairly good quality. The roads have steep grades and are difficult to maintain. Railroad lines enter the highlands only along the wider valleys and are at an inconvenient distance from many of the towns. Parts of Union, Hartland, and North Stonington are 10 miles from any railroad, and many farms in Killingworth, Salem, Goshen, Ashford, Canterbury, and Ledyard are nearly as inaccessible. The result is that the population of certain hill towns has actually decreased. During the decade from 1890 to 1900 ten towns out of twenty-six in Litchfield County showed a decrease in population and ten out of thirteen towns in Tolland County suffered a net loss in population of 1,400. At the present time a new era seems to be dawning for rural Connecticut, partly as a result of improved methods of farming and of the introduction of the practice of scientific forestry, but more largely owing to the fact that the farms of the highlands are being purchased for summer homes and estates. For this purpose an abundant supply of good water is essential. In fact, the water resources of Connecticut form one of its chief commercial assets, and a knowledge of their character and occurrence has become a matter of great practical importance.

CHAPTER II.

GEOLOGY.

OUTLINE OF GEOLOGIC HISTORY.

Very little is known of the early geologic history of Connecticut. It is probable that some of the gneisses and schists date from a time before any living forms existed upon the earth, but no fossils older than the Triassic have been found in the State, and it is therefore impossible to determine definitely to what age the pre-Triassic rocks belong. Their position in the time scale can, however, be determined approximately by comparing them with similar rocks in regions where their relations are known. This study of adjoining regions, taken in connection with the detailed study of the structure of the rocks themselves, indicates that the crystalline rocks of Connecticut have a long and complicated geologic history.

Pre-Cambrian rocks are represented in the State by the Becket gneiss, but no data are at hand to determine definitely the origin or age of this formation. Its component parts have been so completely altered by changes that have taken place since their deposition that all evidence of value for determining their original character has been destroyed. The character of the rocks overlying the Becket gneiss indicates that a sea extended over a large part of Connecticut during Cambro-Ordovician time and that the Stockbridge limestone and associated quartzites were deposited in that ancient water body. Such an accumulation of material implies the wearing down of land masses and suggests that lands of considerable elevation must have existed to the east of the present shore line.

The long interval between the close of the Ordovician and the beginning of the Mesozoic time has left no legible records of deposits that can be assigned to any definite geologic period. The great thickness of Devonian sediments to the west suggests a New England mountain range of considerable height which furnished material for the sedimentary strata.

One series of events, however, is abundantly attested, namely, that igneous intrusions occurred frequently in the interval between the Ordovician and the Triassic periods, resulting in the formation of numerous veins and dikes of quartz and granitic and basic rocks. The nature of these intrusive masses indicates that they have been

brought to the surface by the removal of thousands of feet of sediments. The particular date of any of these igneous intrusions is unknown, but their effect is well shown, and it is not at all unlikely that part of the molten rock reached the surface and was represented by volcanic activity, all traces of which have disappeared.

The geologic records show also that at different times between the Ordovician and the Triassic there were important movements in the earth's crust which resulted in the metamorphism of all the existing rocks in the State. Just when these profound changes took place is unknown, but the rocks are believed to have been involved in the great earth movements which produced mountains at the close of the Archean, Ordovician, and Carboniferous periods.

That many changes took place in Connecticut during the time from the Ordovician to the close of the Carboniferous is shown beyond doubt by an examination of the highland areas.

These rocks are chiefly schists and gneisses, and accordingly have structures indicating that they have been profoundly changed from their original sedimentary or igneous character. The original component minerals have been rearranged, stretched, and drawn out in lines; new minerals have been produced; parts have been fused and recrystallized. Instead of horizontal layers or uniform igneous masses, we find twisted and broken rock with layers, bands, and ribbon structures in every conceivable position. This tangle of structure is further complicated by the presence of dikes, seams, and veins which have made their way into the rock at different stages of its history. In looking at this confused mass of rock which forms the Connecticut crystallines, it seems apparent that it has taken part in manifold changes which went on in the earth's crust for ages. This very complexity of structure is an important aid in determining the relative age of the rocks, for it is evident that in general the oldest rocks must have been affected by the greatest number of disturbances, and accordingly the rocks of one age may exhibit structures not found in those of succeeding ages. In the absence of other criteria the geologist is forced to fall back upon this. These rocks are like a parchment on which writing after writing has been placed at different times by different hands, without at any time completely erasing the previous inscriptions. Little wonder that we have difficulty in deciphering the original writing.

Such composition and structure as is described above can be produced only at very great depths in the earth (probably below 20,000 feet) where rocks are so deeply buried that, whatever the lateral stress, they will not adjust themselves by breaking, but by plastic deformation. It is therefore certain that, whatever the age of the crystallines, mountain ranges perhaps rivaling the Alps in height and ruggedness once occupied central Connecticut; and when we examine the rocks of Satans Kingdom, or the Quinnebaug Valley, or the Connecticut gorge below Middletown, or indeed any part of the area of crystalline rocks, we are studying the roots of lofty land masses composed of strata deposited during part or all of the Paleozoic era.[a]

The land at the close of the Carboniferous was probably marked by rugged topography—the hills and valleys making prominent scenic features. During Triassic time these elevations were removed and the material from the crumbling hills was built into the sandstones of central Connecticut.

[a] Rice, W. N., and Gregory, H. E., Manual of Connecticut geology, 1906, pp. 80, 81.

The Triassic rocks are very much younger than any of the crystalline rocks exposed within the State; in fact, it is possible that no rocks were formed for a long period before the deposition of the lowest sandstone stratum. Where the ancient crystalline rocks and the Triassic rocks come into contact there is a marked unconformity, the sandstones lying upon the upturned edges of schists and gneisses of ancient time. The Triassic sandstone was deposited in water which was fresh or perhaps brackish, and a great deal of it was deposited in water which must have been shallow. The presence of animal life is indicated by the fossils found in the sandstones and shales. Skeletons of dinosaurs have been recovered and thousands of tracks of these strange animals have been found in the quarries of the Connecticut Valley. The shales at Saltonstall and Durham and elsewhere contain abundant remains of fish.

During the long time throughout which the Triassic sediments were being deposited volcanic eruptions formed widespread lava flows extending from New Haven to the northern line of the State. Outbursts of lava occurred at three different times and the fields of basalt which represent these flows are separated by considerable thicknesses of shale and sandstone, indicating periods of volcanic activity followed by long periods of quiet.

The sandstones and lavas of Connecticut were laid down in an approximately horizontal position, but at a date later than the Triassic the flat-lying beds were broken by a series of faults extending diagonally across the central lowlands. Displacement along these fault lines formed a series of giant blocks, composed of sandstone and trap, that were elevated on the west side and depressed on the east. The topographic result was a series of ridges with steep westward escarpment and gently sloping eastward face.

During Cretaceous time the entire region seems to have been worn down to a plain practically at sea level and sloping gently from northwest to southeast. Hills stood above the plain, but not to such an extent as to give the country a rugged topography. The southern part of the State at this time was probably covered with sediments deposited in a Cretaceous sea which extended to the latitude of Hartford. The result of this long period of erosion was to reduce the inequalities produced by the uplifting of the blocks of sandstone and lava and to lessen the contrast between highland and lowland areas.

Near the beginning of the Tertiary period the area now forming the State was uplifted and the streams which had been wandering across the Cretaceous plain were revived and began once more to cut their channels and to carry sediment to the sea. The result was to bring into relief all the harder and more resistant rock masses by removing the softer material. For example, in central Connecticut the areas of resistant trap stand above the sandstone plain as ridges

whose length and shape had been previously determined by the direction of the fault lines. In the same way the softer Cretaceous strata along the coast seem to have been entirely removed and the less resistant limestone of the Housatonic Valley reduced to a narrow lowland. As a result of this long period of stream erosion during Tertiary time, the topography of the State acquired the larger general features of the present time.

During the Pleistocene ("Glacial") epoch the topography of Connecticut was again remodeled. The continental ice sheet which covered the northern part of America extended entirely across New England. Its thickness was great, the power urging it on was irresistible, and accordingly the landscape was molded in a characteristic manner. The loosened soil covering was removed from the rocks and the rocks themselves were reduced in height. They were grooved and scratched and polished by the pebbles embedded in the ice. A great quantity of material was removed permanently from the area and carried to Long Island. Although the larger features of the topography left by Tertiary erosion were little changed when the glacier disappeared, the details were greatly modified. Instead of the soil formed by the decomposition of the rocks, the glacier left two types of surface covering—glacial till, an unassorted and unstratified mass of rocks, bowlders, clays, and sands, differing widely in size and in composition, and stratified drift composed of layers of sands and gravel. The till came directly from the material carried by the glacier. The stratified drift was deposited by the waters from the melting ice mass. The distribution of this glacial material over the entire region modified the shape of hills, filled valleys, blocked drainage courses, rearranged stream channels, and left many depressions filled with bodies of water, so that although the main streams, like the Connecticut and the Housatonic, are now flowing in courses inherited from Tertiary time, yet the smaller streams owe their present arrangement very much to the changes produced by glaciation. Waterfalls, lakes, ponds, and swamps are also records of the Pleistocene ice invasion.

DESCRIPTIVE GEOLOGY.

INTRODUCTION.

The occurrence of ground water and the methods of its recovery are determined by the structure of the rocks, and therefore a knowledge of the character of the geologic formations of a region is essential to the well driller and to the well owner if he desires to attain satisfactory results at minimum expense. In Connecticut a well in mica schist may need to be of different construction from one in sandstone and will yield water differing in amount and in quality. Wells in till are usually shallow and of large diameter; those in

stratified drift are particularly liable to contamination; those in sandstone and shale rarely yield water that is suitable for boilers. Thus in many ways the rock formations represented in the State determine the nature and value of the water supply.

In Connecticut three widely different rock groups must be taken into account by the well driller—the crystalline rocks forming the western and eastern highlands; the sandstones of the central lowland; and the deposits of sands, gravels, and clays which overlie all the rocks of the State. The sandstones, shales, and conglomerates are of Triassic age, as is shown by the numerous fossils contained in them. The gravels and other surficial deposits are of Pleistocene age. The crystalline rocks are of much greater antiquity, but owing to the absence of any definite marks of identification they will be referred to simply as pre-Triassic.

CRYSTALLINE ROCKS.

DISTRIBUTION AND CHARACTER.

With the exception of the area underlain by Triassic strata, the entire State of Connecticut is occupied by crystalline rocks of very great age. They are of two types, igneous and metamorphic, both widely different from the sediments of the valley lowlands.

Igneous rocks are those which have been molten and have solidified from cooling. They are accordingly composed of crystals, closely fitted and interlocking, instead of being made up of grains or fragments of material, as are sandstones. The many different textures shown by these igneous rocks were determined by their rate of cooling, and in accordance with this principle fine-grained granites and granite porphyry have been formed. Unchanged igneous rocks are rare in Connecticut outside of the traps of the Triassic region. They occur as veins, dikes, and small bosses, mostly of granite and related rocks. A few diabase dikes are distributed along the borders of the lowlands. The masses of unaltered igneous rock within the ancient crystalline areas are so small that it has not been found desirable to indicate them on the geologic map of the State.[a]

Metamorphic rock constitutes practically all of the crystalline areas in Connecticut. Rocks of this type have been profoundly changed from their original condition either as igneous or sedimentary. The change in some of these rocks is merely a hardening, as when shales are baked by the intrusion of a trap dike. But the metamorphic rocks of the State as a whole show much more complete alteration. Their mineralogical composition has been changed, their structure has been destroyed, and fossils which they may

[a] Bull. Connecticut Geol. and Nat. Hist. Survey No. 7, 1907.

have formerly contained have been obliterated. The changes have been so great that the rocks bear little resemblance to their former appearance, and with some of them it is impossible to determine whether the original material was igneous or sedimentary.

The metamorphic rock masses existing within the State are crystallized limestone (marble), quartzite, phyllite, schist, and gneiss. Marble is a metamorphosed limestone, in which the grains of the original rock have been converted into crystals. Quartzite is a sandstone which has been made firm and compact by filling in the spaces between the sand grains with quartz. Phyllite is usually an advanced stage in the development of slate, which in turn is made of mud shales and related rocks. Schists and gneisses are so widespread within the State that they might be said to constitute the bed rock of the region. Twenty-three varieties of gneiss and eight varieties of schist are shown on the Connecticut geologic map. Schist is a term used to indicate the structure of the rock, not its composition, and represents an extreme stage of metamorphism in a rock which may have been originally igneous, sedimentary, or metamorphic. In schists so far has metamorphism proceeded that new minerals have been made, particularly mica, and a complete rearrangement of the mineral particles has taken place.

The value of the crystalline rocks as water carriers is determined by the facts that they are very dense, nonpermeable rocks, that structures of slatiness and schistosity are developed in them, that they are traversed by numerous joints in many directions, and that they are cut by large or small faults.

Schists are characterized by cleavage planes which enable the separation of the rock into irregular layers of small thickness. The structure which admits of the splitting of the rock in this manner is called schistosity and owes its origin to the parallel arrangement of micas and other flat minerals whereby separation takes place in one direction much more readily than in others. Schists always contain an abundance of mica, but they contain also other minerals in large amounts. Feldspar is invariably present, and a typical mica schist consists essentially of feldspar, mica, and quartz. The names hornblende schist, quartz schist, kyanite schist, etc., used in the following pages, indicate the prominence of certain minerals. Most of the Connecticut schists are believed to be the metamorphic equivalents of sedimentary rocks, the Hoosac ("Hartland") schist, for example, having previously been a series of sandstones, shales, and limestones, much like the present sediments of the Triassic belt.

Gneiss, like schist, is a term which refers only to the structure of a rock and implies the existence of a series of roughly parallel breaking planes along which the rock may be separated into slabs of various sizes. The development of schistosity is alike in gneisses and schists,

but gneiss is more massive and is commonly the present equivalent of former igneous rocks. The production of gneiss from granite has taken place within the Connecticut area on a large scale. Granite masses have been stretched and squeezed so that instead of being of uniform texture and massive structure they are drawn out into sheets and definite layers. Practically all of the granite quarried within the State is granite gneiss, the gneissoid structure of which is an important factor in successful quarrying.

When schists or gneisses are exposed to the atmosphere the planes of schistosity often become definite cracks and open fissures into which water may descend and collect in amounts sufficient to supply wells or springs. It is this capacity to carry water which makes a detailed study of the structure of rocks a matter of practical importance.

JOINTS.

Rocks do not as a rule present an unbroken surface over any considerable area, but are traversed by cracks, which vary in size from those that are scarcely visible to those that are several inches in width. These cracks or "seams," as they are called by drillers and quarrymen, are technically joints. They are the results of mechanical action in rocks, which breaks them into more or less regular polygonal blocks separated by open spaces, and they are therefore of great importance when water-storage capacity is considered.

The most common type of joints includes those which are approximately vertical and cross each other at various angles, giving the rock surface the appearance of a rough screen or network. The prevalence of vertical jointing is shown by the fact that the inclination of about seventy-five measured joint planes in the Connecticut crystalline rocks was found to average 74°, forty of the joints being practically 90° from the horizontal. Another set of joints in the crystalline rocks runs more or less parallel to the surface of the rock. Some of these joints correspond to gneissoid and schistose structures, but many others represent entirely different planes of cleavage. In the gneissoid granites, as at Maromas and Glastonbury, these horizontal joints occur, but they vary considerably in their extent, number, spacing, and direction, as well as in width of opening, a variation which seems to depend primarily on the character of the rocks which they traverse. In the gneisses, particularly in gneissoid granites and granodiorites, the horizontal joints are very well developed and constitute the so-called "bedding" of the quarrymen. In the schists and the less massive gneisses horizontal jointing is poorly developed and in places even lacking. The character and number of vertical joints also depend on the nature of the rock. Certain rocks seem to be thoroughly shattered and broken by vertical joints into small

wedges and blocks a fraction of an inch in diameter. Other rocks, like pegmatites, may extend for 25 to 50 feet without being marked by a prominent line of breaking. A good illustration of the difference of the jointing in two types of rock is seen in the Milford chlorite schist, where much fractured schistose and slaty varieties occur immediately in contact with fairly compact masses of altered diabase.

FAULTS.

Fractures along which more or less vertical movement has taken place are called faults and have been frequently observed in outcrops of crystalline rock. Many of the fractures extend to considerable depths and may appear on the surface as single lines or as zones of closely packed joints or of shattered rock. Much ground water may be stored in zones of faulted rock, and the open spaces afforded for the movement of water make fault lines of great value as channels for spring waters and supplies for wells.

TRIASSIC SANDSTONE AND TRAP.

DISTRIBUTION.

The Triassic rocks of the State occur in two areas—one extending from the Massachusetts line to Long Island Sound, with a breadth of about 20 miles at Thompsonville and narrowing at New Haven to the width of the harbor, the other underlying the towns of Southbury and Woodbury. Both of these areas are links in a broken chain of similar Triassic deposits which extends from North Carolina to Minas Basin, on the Bay of Fundy, a distance of 1,200 miles, and which covers altogether 10,000 square miles.

STRATIGRAPHY.

The relation between the Triassic strata and the ancient crystalline rocks is seen at Roaring Brook, in Southington, where sandstone lies unconformably upon the upturned edges of the Hoosac ("Hartland") schist. A general study of the Triassic areas of the Atlantic coast leads to the belief that the Connecticut areas are parts of a much larger expanse of Triassic rocks and that they owe their present existence to the fact that they have been dropped down as a result of faulting, and thus protected from the erosion which removed the adjoining areas exposed at higher levels.

The rock types existing in the Triassic area are two—the lavas (basalts) and intrusive sheets and dikes (diabase), rocks which are called popularly "trap;" and the sandstones, which range in texture from fine shales to extremely coarse conglomerates. The stratigraphic series in the Triassic of Connecticut consists of three lava

flows with sedimentary strata below, between, and above them. Their relations are shown by the following table:

Stratigraphic succession in Triassic rocks of Connecticut.

	Feet.
Pre-Triassic metamorphic rocks.	
"Lower" sandstones	5,000–6,500
"Anterior"[a] (lower) trap	250
"Anterior" shales and shaly sandstones	300–1,000
"Main" (middle) trap	400–500
"Posterior" shales	1,200
"Posterior" (upper) trap	100–150
"Upper" sandstones	3,500

The "Lower" sandstone varies in texture from a fine-grained rock in the vicinity of Avon and Granby to a coarse conglomerate in which some of the pebbles exceed 2 feet in diameter. Where typically exposed in the quarries at Fair Haven the rock consists of fragments from the bordering crystalline rocks, including abundant crystals of feldspar, pebbles of quartz, fragments of porphyries, gneisses, and schists. Great variation is shown in the composition and structure of the beds, and abrupt changes in the character of the rock are observed at many places. In general the stratification is uneven and irregular, and the coarser and finer materials have rather the character of lenses than of uniform beds of wide extent.

The "Anterior" and "Posterior" sandstones contain a much larger proportion of shales than the "Lower" sandstones; in fact, shales and shaly sandstones are characteristic of these formations. In certain places, as east of Southington, an impure limestone occurs, and in a number of localities there is a slightly bituminous black shale. The stratigraphic position of the black shale is 50 to 100 feet above the "Anterior" trap sheet and at different levels between the "Main" and "Posterior" traps. The presence of these beds of shale has an important bearing on the problem of water supply. (See p. 109.) Fossil fish have been discovered in them at Saltonstall Lake, Rocky Hill, Durham, and other localities.

The "Upper" sandstones, consisting of sandstone and shale, with conglomerate locally developed, constitute the Triassic strata east of the central trap ridge. It is in these sandstones that the quarries at Portland and Long Meadow are located. In certain localities the "Upper" sandstone has characteristic features, but as a rule it is not a distinct formation. As stated by Davis,[b] "the Anterior, Posterior, and Upper sandstones and shales are seldom distin-

[a] Owing to the monoclinal faulting which has broken the Triassic strata into eastward-tilting blocks, the traveler going from west to east across the Connecticut lowland comes first to the lowest and oldest lava flow, next to the middle, and last to the uppermost. Hence the terms "Anterior," "Main," "Posterior," first used by Percival.

[b] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, p. 139.

guishable." It is also true that these three formations are practically indistinguishable from the "Lower" sandstones.

The three lava flows—"Anterior," "Main," and "Posterior"—are identical in chemical and mineralogical composition and are manifestly of closely similar origin. They are flows of basalt from unknown sources. The "Anterior" trap is broken into a series of small hills and short ridges at Saltonstall, Totoket Mountain, Lamentation Mountain, and other places, and disappears in the vicinity of "Newgate Prison," in East Granby. This trap sheet is comparatively dense, but is vesicular on the upper surface, and at Lamentation Mountain it contains an "ash bed" of fine lapilli, 30 feet thick. The "Main" trap sheet is made up of two or more flows with a combined thickness of 400 to 500 feet and constitutes the most prominent topographic feature of central Connecticut, forming the conspicuous ridges beginning at Saltonstall and extending through Meriden and Farmington and into Massachusetts, where they include Mount Tom and Mount Holyoke. The "Posterior" trap follows the "Main" trap sheet in general alignment and has similar characteristics, but at only a few places does it become an important topographic feature. An excellant view of the "Posterior" trap and the underlying sandstones may be obtained at the city quarry, Hartford, immediately adjoining the buildings of Trinity College.

In addition to the three lava flows there is a series of intrusive trap sheets and dikes composed of diabase. East and West rocks at New Haven, Gaylord Mountain, the ridges east of Canton, and the Barndoor Hills are examples.

JOINTS.

Both the sandstones and the traps of Connecticut are traversed by many prominent joints, which form reservoirs for ground water. Where exposed in quarries the sandstone is seen to be cut by numerous joints and open fissures, so that even in the most favorable localities it is impossible to quarry slabs of stone of very large size. The principal joints are nearly vertical and intersect each other at fairly wide angles, so that the finer-grained sandstone and the shale break in more or less uniform blocks. In the Hartford quarry the shale is traversed by two prominent sets of cracks, which enable the workmen to remove diamond-shaped blocks about a foot in diameter. The conglomerate, especially where it contains large quantities of quartz, exhibits much less uniformity in jointing than the finer-grained rocks. The blocks into which it breaks are wedges and rude polyhedrons of such a variety of form as to make it impossible to predict the location of definite division planes. Many of the joints in the sandstone are weathered to great depth and furnish ready passage for water. (See pp. 73–74, 111–113.)

The trap rocks are of such uniform texture and of such fine grain that the jointing is exhibited on a very elaborate scale. Usually the joints are barely visible, but in a few places they are widely open and some of them have been filled with secondary material. The intrusive traps, and some of the lava flows as well, show a decided jointing at right angles to the plane of cooling, which gives a rudely columnar structure to the rock. In the New Haven region the columns are beautifully developed at Rabbit Rock, and some of the dikes in the Fair Haven tunnel show a regular and uniform system of joint cracks.

Perhaps the most convincing evidence of the abundance and influence of joints in trap is furnished by exposed cliffs below which is a talus slope of broken trap formed by joint blocks derived from the ledge above. Practically every high trap ridge in the State is flanked by such jumbled masses of fragments, the size and shape of which is determined by the direction and spacing of the cracks in the ledge. On the exposed edges of cliffs the joints furnish ample facilities for the free circulation and storage of water. In fact, where the bed rock is trap these cracks contain almost the only water supply within reach of wells.

FAULTS.

The sandstones and lavas of the Triassic area were laid down in a horizontal position. They no longer retain that attitude, however, but dip to the east at an average angle of 15° to 20°. In a few places the strata lie practically flat, and locally the dips are as high as 40°. These dips are due to the fact that the region is crossed by a series of fault lines which have cut the strata into blocks that are tilted to the east. Faults are joints or cracks in rock along which movement has taken place and which, accordingly, disturb the continuity of the rock much more profoundly than simple joints. In the lowland area twenty-five faults have been traced which extend for 5 miles or more, and one fault extending between Hanging Hills and Lamentation Mountain extends northeast and southwest for 40 miles. Innumerable smaller faults exist and may be observed in practically every outcrop of trap or sandstone. In places they occur so abundantly and are so closely placed that the rock appears to be shattered into small fragments. The amount of slipping which has occurred along these fault planes varies from a few inches, observed in quarries and railroad cuts, to several thousand feet in the great diagonal faults which have brought the "Lower" sandstones of Lamentation Mountain up to the level of the "Posterior" trap. The uplift in most of these faults is on the east side of the fault line, which accounts for the eastward dip of the strata and for the westward-facing cliffs. If the faults extended in the direction of the strike of the strata a series

of parallel ridges would be exposed, marked by prominent cliffs of erosion on the west side. But the faults have traversed the formations obliquely, most of them from northeast to southwest, with the result that the erosion has produced a series of blocks which are not in alignment but are offset to one side or the other and separated by passes and gaps and notches.

The small Triassic area in the Pomperaug Valley presents features practically identical with those in the central lowland, and therefore requires no separate description.[a]

PLEISTOCENE DRIFT.

DISTRIBUTION AND GENERAL RELATIONS.

The glacial deposits of Connecticut form a mantle covering the bed rock practically everywhere. It is doubtful if bare rock is exposed over one-tenth of 1 per cent of the surface. The drift in thickness varies from a mere film to masses 300 feet in depth which have obliterated ancient stream courses. It is not quite so thick near the Sound and on the highlands as in the major valleys, and the rock ledges are confined for the most part to the summits of ridges and projecting cliffs now partly covered with talus. The disintegrated rock material formed throughout earlier geologic ages was removed by the glaciers, so that in general the rock surface where exposed is firm. Immediately overlying the solid rock, but with a marked unconformity between, is the glacial drift. The surface material as a rule has not originated from the rock on which it rests, and it may be entirely different in composition as well as in texture. Drift fragments of gneiss may be in immediate contact with shale, and bowlders of sandstone and trap may form the soil above ledges of mica schist. The fact that the bed rock is everywhere covered with glacial drift is one of the most important factors in the underground water problem of Connecticut, for the drift acts as a reservoir to feed water into the joints and cracks of the bed rock underneath. (See p. 142.)

CHARACTER OF MATERIAL.

Two types of glacial material are exhibited in the State—till and stratified drift. The till was made directly by the glacier and consists of deposits which are characteristic and quite unlike those made by water or wind. Glacial ice does not sort material, and the result is that till is composed of bowlders, sands, clay, and pebbles of all sizes, confusedly intermingled; and the same outcrop may show a heterogeneous lot of bowlders mixed with finely ground

[a] For a complete discussion of the faults of the Woodbury-Southbury region see Hobbs, W. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, pp. 7–162.

clay and sand. The bowlders may be securely bedded in rock flour in such a manner as to form "hardpan," which is scarcely less friable than artificial concrete and which furnishes little access to water; or the whole mass may be composed of bowlders and sand with large spaces between the fragments. Ordinarily the till is spread more or less uniformly over a region with a thickness depending on the character of the underlying topography, but here and there it is built into mounds (drumlins) which have been overridden by the ice, much as sand bars are formed in rivers.

Most of the rock fragments composing the till have not been rounded by water, and although much worn they are subangular and in many places polished and grooved and striated. The innumerable bowlders strewn over the surface of the State, built into fences, or used for foundations are parts of the till left by the retreating glacier.

Stratified drift consists of rounded fragments of sand and gravel deposited by water from the melting ice and differs little in appearance from deposits made by rivers or by the ocean. It differs from till in being stratified—that is, it is arranged in layers of fine and coarse material; and although the original fragments are the result of the grinding action of the ice sheet, the present position and structure of the drift are due to glacial waters. Stratified drift usually forms sand plains, and is confined chiefly to valleys and lower levels. Certain long winding ridges of stratified drift, indicating the channels of preglacial streams, are called eskers, and in some places the stratified drift takes the form of knobs, short ridges, and kettle holes, which are due to water action under conditions of confinement.

CHAPTER III.

OCCURRENCE AND RECOVERY OF GROUND WATER.

CIRCULATION OF GROUND WATER.

THE WATER TABLE.

The term "ground water" is used in referring to water supplies obtained from wells or springs, in contrast with those derived from streams and lakes. The ground water represents that part of the rain or snow which penetrates into the soil, while the remainder of the precipitation is delivered directly to surface streams, evaporated, or absorbed by vegetation.

The clearest conception of the circulation of ground waters may be obtained by considering the material in which they occur to be of a uniform character. Every one is familiar with the fact that a hole dug in the sandy beach of the sea or of a lake will fill with water to the level of the sea or lake water, and in a sea-beach hole the level of the water will lower as the tide goes out. As holes or wells are dug at greater distances from the shore and at higher elevations the level of the water in the wells is found to rise above that of the surface of the lake, river, swamp, or other body of water with which the comparison is made. The height to which the water will rise at any point in the ground is known as the height of the water table at that point. The water table therefore represents the upper limit of a zone saturated with water, above which the ground is relatively free from water except immediately after rainfall. It is the surface of the sea of ground water, and it is also called the "ground-water level."

The water table has a surface rising and falling with the land surface, but with smaller differences of elevation. The water has the highest elevation on the hills and the lowest in the depressions, but stands farthest from the surface of the ground on the hills and rises nearest to the surface in the depressions; where these are deep enough it reaches the surface to form swamps, lakes, and streams. Where the ground is perfectly level and uniform in character the level of the water table is uniform, but where changes occur in the surface elevation the water flows from the higher to the lower points, and there is thus a constant movement of the ground water from the hills toward the valleys. With surface waters this movement is unrestrained and the water immediately runs off the hills; but the movement of ground waters is very slow, owing to the frictional resistance to the passage

of the water through the small openings of the soil and rock. This slowness of movement makes possible the existence of shallow dug wells on hills, and it is also the cause of the constancy of flow of streams and springs throughout the year. If the ground water moved as freely as the surface water the streams would have exceedingly large flows immediately after heavy precipitation and would be dry in the intervals between rains.

MOVEMENT OF GROUND WATER.

The movement of ground water is due to the force of gravity, and accordingly tends to take a vertical direction. After a rainfall the water absorbed by the ground gradually percolates downward through the soil until it reaches the water table, where the motion of the sea of ground water instead of being vertical is mainly in the same direction as the slope of the surface. This slowly moving body of ground water finally comes to the surface. Some of it emerges as springs or as a succession of small seepages along the banks of streams, but a considerable proportion of it probably enters streams and lakes

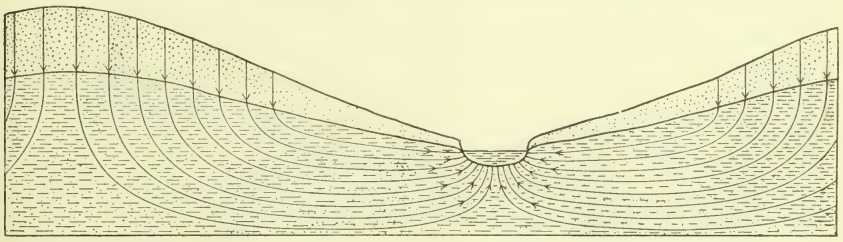


FIGURE 5.—Diagrammatic section illustrating seepage and growth of streams. Lines with arrows are lines of flows.

below the water level. The general directions of flow of ground water and the manner in which streams are supplied are indicated in figure 5.

Although the circulation of ground water is in a general way as stated above, it happens that natural conditions rarely afford a uniform material in which the level of the water table may be predicted at any point. The ground is nearly everywhere made up of materials varying in character and offering different degrees of resistance to the circulation of water. In Connecticut the ideal conditions are most nearly realized in some of the flat sandy plains of the Connecticut Valley.

POROSITY.

The circulation of water in any material is directly dependent on the amount and character of the openings in that material, and these openings may be in the form of small pores, of long flat joints or other fractures, or of irregular rounded and tubular openings varying in size.

All rocks are composed of masses of separate particles or grains which do not touch each other at all points, small irregular openings occurring between the grains. This pore space, called "porosity," varies greatly in different materials and is largest in rocks that are composed of rounded grains laid down under water and least in rocks that have solidified from a molten condition. The porosity of a rock is expressed as a percentage of the entire volume. If 100 cubic feet of sandstone can absorb 20 cubic feet of water the rock is said to have a porosity of 20 per cent.

The following table gives the percentage of pore space and the amount of water absorbed per cubic foot by various sorts of rocks:

Porosity of different rocks.

Rock.	Percentage of pore space.	Water absorbed per cubic foot (quarts).
Sandstone	4.81	2–6
Do	28.28	
Limestone	.14	$\frac{1}{4}$–$1\frac{1}{4}$
Do	13.36	1–5
Marble	.184	
Do	3.578	
Granite	.969	$\frac{1}{100}$–$\frac{1}{4}$
Do		
Slate	.099	
Do	.304	
Chalk		4–8
Sand		8–10
Clay		10–12

These figures represent the ordinary limits of the porosity of the rocks and are derived from different sources.

PERMEABILITY.

The permeability of a rock is a measure of its ability to transmit water and is the most important factor in determining its value as a source of water supply. Permeability is dependent on the amount and character of porosity and on the existence of other openings, such as joints and other fractures and the small openings formed by escaping gas in certain lava flows.

In order that water may readily pass through a rock it is necessary that the openings be of appreciable size and have good connection with one another. In openings of small size the flow of water is strongly opposed by friction and by the attraction between the sides of the openings and the water, which in very small openings is sufficient to cause all the water to adhere to the sides as if glued. The effect of small size of openings is well shown by clays such as the brick clays of the Connecticut Valley, which may absorb water equal to 40 per cent of their weight, indicating a high porosity, but which allow water to pass through only with extreme slowness. In clays

the constituent particles are so small and of such angular shape that the individual pore spaces are exceedingly minute, though in the aggregate of considerable volume. In sandstones the openings are so large as to allow relatively rapid flow. In general the size of the pores and consequently the permeability decrease with decrease in size of grain. Slichter [a] has made the following calculations, based on experimental work, of the velocity and amounts of ground water passing through materials of different grades.

Velocity of ground water in materials of different grades, pressure gradient 10 feet to the mile.

Material.	Diameter (millimeters).	Distance traveled per year.	
		Miles.	Feet.
Fine sand	0.2	0.010	52.8
Medium sand	.4	.041	216.0
Coarse sand	.8	.16	845.0
Fine gravel	2.0	1.02	5,386.0

Flow of ground water in materials of different grades through a bed of vertical cross section 200 by 1,000 feet, sloping 10 feet to the mile.

	Cubic feet per minute.
Fine sand	5.5
Medium sand	22
Coarse sand	87
Fine gravel	546

These determinations assume a uniform size of grain, a uniform porosity of 32 per cent, and a temperature of 50° F.

The law of flow through homogeneous porous materials is that the quantity of flow varies as the square of the size of the soil grain, other factors being constant. This law is based on the assumption that the grains are unconsolidated, but in all sandstones there is more or less cementing material which binds the grains together and necessarily decreases the amount of pore space. The more highly cemented the rock the less the porosity, although the cementation itself is an indication of former free circulation, as it is due to the deposition of mineral matter from water. Other factors influencing the amount of flow are variations in porosity and in temperature.[b] The flow at 70° F. is about double that at 32° F., owing to the fact that the viscosity of water decreases rapidly with rise in temperature.

The influence of joints and other fractures is of increasing importance as the porosity and size of the pore openings decrease, and in thoroughly crystalline rocks the only water circulation of consequence is through fractures. The rapidity of flow through joints is

[a] Slichter, C. S., Motions of underground waters: Water-Supply Paper U. S. Geol. Survey No. 67, 1902, pp. 29, 30.

[b] Slichter, C. S., op. cit., p. 25.

not known, but it is undoubtedly much greater than through the pores. Owing to the differences in the permeability of rocks water has decidedly different rates and amounts of flow in adjacent materials. The main flow of water is confined to the most permeable formation, other conditions being equal.

Most underground waters yielding supplies of economic importance are under more or less modified artesian conditions; that is, they follow definite inclined channels or zones, inclosed by material more impermeable to water than that carrying the water, and rise to some extent above the level where they are struck.

ARTESIAN CONDITIONS.

The term artesian was originally applied only to wells which yielded a flow of water rising above the surface of the ground, but it is now frequently used for any water that will rise above the point where it is struck, indicating that it is under pressure or head. The ideal conditions for artesian circulation are two inclined layers of imper-

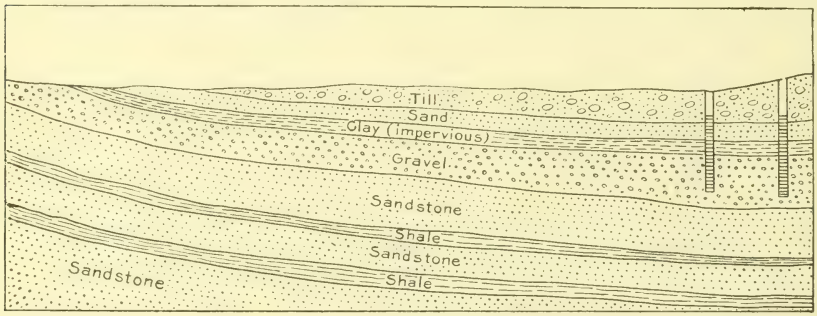


FIGURE 6.—Diagram illustrating artesian conditions where water does not rise to the surface.

vious material inclosing a layer of permeable material saturated with water for which there is no escape below the point where the water-bearing material is tapped. If the upper impervious layer is then penetrated in some manner, as by a drill hole, so that the saturated layer is entered at some point below the level at which the water naturally stands, the water will rise in the drill hole to a height determined by and nearly equal to the level at which the water stands in the water-bearing material. Figure 6 represents the conditions under which flowing wells may occur and under which the water will rise under artesian pressure to a certain level, but will not reach the surface.

The level to which water will rise in the well will always be somewhat lower than that of the water table in the permeable material, owing to the loss of head due to friction during the passage of the water to the well, and this difference in level will increase with increase of distance from the source of supply.

The conditions on which artesian flow depends may be summarized as follows:

1. A porous and permeable stratum capable of absorbing and transmitting large quantities of water. In certain localities planes of fracture may transmit the water rather than a porous stratum.

2. Relatively impervious materials above and below, preventing the escape of water from the porous stratum. Such conditions might be realized by a bed of sandstone between two beds of shale or by a layer of sand resting on massive granite and overlain by clay.

3. An exposure of the porous stratum where it may absorb water supplied either by direct precipitation or by percolation of waters falling on porous material above.

4. An inclination of the water-bearing stratum so that gravity may force the water down and produce an artesian head. This inclination may be due to the manner of original deposition, but is ordinarily caused by a displacement of the strata after deposition.

5. A lack of easy escape for the water at lower points than that where the porous material is penetrated, as the artesian head would be lost if the water had such escape.

6. A sufficient precipitation and absorption to keep the porous material saturated and maintain the artesian head.

Although these conditions are partly realized at many places in Connecticut, they are generally modified by many factors. In the Connecticut Valley the relatively porous sandstone has a marked dip to the east, and it is not uncommon to find a stratum of sandstone confined between two layers of shale. However, these rocks are intersected by so large a number of fractures that the water which can not pass through the fine pores of the shale leaks through the jointed material, destroying the artesian head. At many places in Connecticut a number of springs occur in a relatively straight line, indicating the existence of a fracture plane along which waters are escaping from confinement below. The artesian waters, instead of coming to the surface through artificial wells, are escaping through the openings furnished by nature. Fuller [a] has shown that artesian conditions may occur in such uniform materials as sand, owing to the overlapping of the elongated sand grains.

The fact that the ground water is in a state of continual motion, as shown by various experimental methods, implies that there must be some escape for the water at lower levels than that where it enters. Such natural escape may occur in a variety of ways. In a material of uniform nature, as sand, the surfaces of streams, lakes, and swamps represent the level of ground water at that point and the escape is due to slow seepage. Bodies of water fed in such a way are extremely

[a] Fuller, M. L., Water-Supply Paper U. S. Geol. Survey No. 145, 1905, p. 41.

variable, increasing and decreasing in amount as the water table rises and falls, owing to varying weather conditions. The way in which such streams are fed is indicated in figure 5.

SPRINGS.

A large amount of the escaping ground water emerges at the surface in the form of springs that are usually rather constant in the

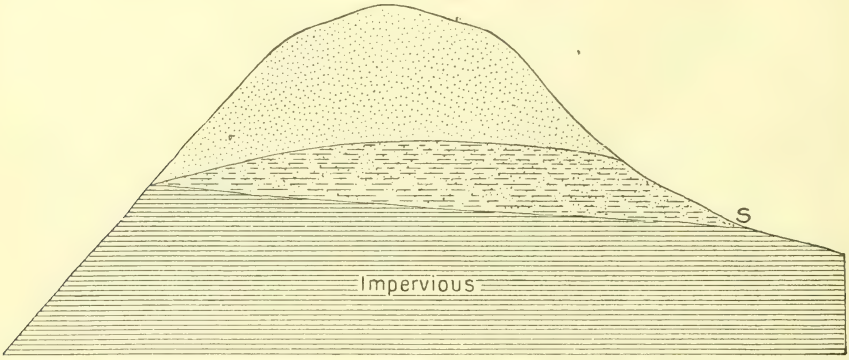


FIGURE 7.—Diagram showing formation of a spring at the outcrop of an inclined impervious stratum. S, Spring.

amount of flow throughout the year. Such springs may represent an escape of artesian waters through fissures, as stated on page 49. Commonly they owe their existence to the presence of a stratum of pervious material overlying an impervious layer (fig. 7). The water penetrating the pervious layer is prevented from moving downward through the impervious layer, whose slope it follows until it finally emerges at the surface at the contact of the two layers.

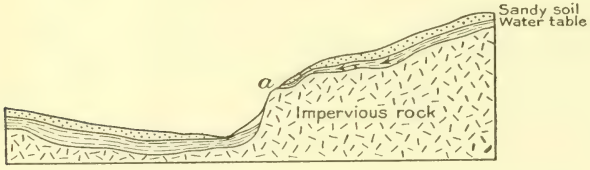


FIGURE 8.—Diagram illustrating manner in which spring may form at contact of soil covering and impervious rock below, when soil is removed by erosion. *a*, Point of emergence of the spring.

Figure 8 represents a type of spring in which the top of a hill is capped by a layer of sandy soil resting on impervious rock. The ground water follows the rock surface until some opportunity is afforded for escape, when the water will emerge as a spring.

FIGURE 9.—Diagram illustrating manner of formation of spring at contact of pervious formation and impervious formation when dissected. A, C, Impervious shale beds; B, porous water-bearing sandstone; M, top of saturated zone; X, point of emergence of spring.

Figure 9 represents the conditions where erosion has cut through the porous stratum and into the impervious layer, affording an easy escape for the ground waters. These diagrams represent two of the numerous ways in which springs may occur. Springs are usually seen issuing as streams rather than as a continuous seepage, both because the stream springs are more conspicuous and because if there is any considerable opening such as a joint crack the water will tend to concentrate in this open channel where the frictional resistance is least.

AMOUNT OF GROUND WATER.

It must be clearly understood that the amount of ground water is limited, as it depends on the amount of precipitation which is absorbed by the ground. The amount that escapes in the form of springs, though also dependent on the amount of precipitation,

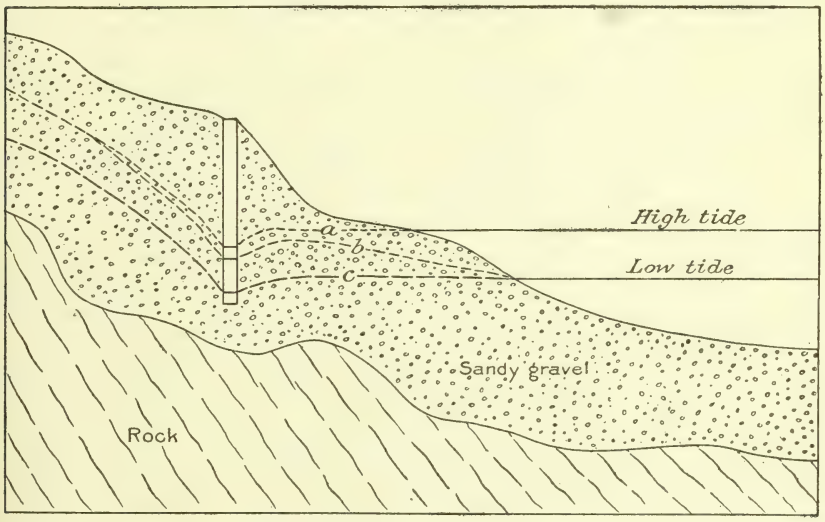


FIGURE 10.—Diagram illustrating effect of tides on water table. *a*, Normal water table at high tide; *b*, normal water table at low tide; *c*, depressed water table during a dry season.

varies relatively less than the precipitation. The amount of precipitation, however, is variable, a dry season being marked by a lowering of the water table and a wet season causing a corresponding rise. The effect of these changes is always marked in shallow dug wells of the ordinary type, the water rising nearly to the top in winter and spring, whereas the same wells will be nearly or quite dry during the latter part of the summer. Springs also are affected to a certain extent by such seasonal changes, but the effect is relatively small as compared with wells. Variations in the level of the water table are also caused by barometric fluctuations, but though these variations may be sufficient to affect the amount of flow of

springs, as shown by F. H. King,[a] they cause no permanent effect on the water supply. In wells near the coast fluctuations of the water table with the rise and fall of the tide are common, as the height of the sea water at high tide gives a slope to the water table differing from the slope at low tide. This is shown in figure 10.

Neighboring wells will usually affect one another, as water can ordinarily be pumped from the wells faster than it can be supplied by the water-bearing material, and the water table is therefore depressed for a varying distance around the wells, so that heavy pumping of one well will cause the lowering of the water level in an adjacent well deriving its supply from the same source. It is not uncommon for an artesian well which had previously given a good flow to lose its flow entirely on the sinking of another well which happened to give an easier escape for the underground waters. As a rule the flow of artesian wells decreases with the lapse of time and the head gradually lowers, indicating that the well is exhausting the supply faster than it is renewed by precipitation, or, in other words, that the water table in the water-bearing material is undergoing continuous depression.

TEMPERATURE OF GROUND WATER.

When the water enters the ground it has a temperature corresponding to that of the atmosphere, but as it percolates downward it is affected by the temperature of the ground and within a very short distance from the surface acquires the temperature of the material through which it is passing. In any region there is a certain depth at which the temperature is constant throughout the year and is practically the same as the mean annual temperature of the region. In Connecticut this depth is 50 to 60 feet, and the mean annual air temperature is 47°, so that waters at about 50 feet below the surface will have this temperature. Most of the Connecticut well waters come from much shallower depths, and consequently have temperatures above or below this average, depending on the season of the year.

Below the level of constant temperature there is a fairly uniform increase of temperature with increase of depth, amounting to about 1° F. for every 60 feet of depth. It is a common belief that the deeper the well the colder will be the water, but it will be readily seen that on this basis beyond a depth of 50 feet the deeper the well the warmer will be the water. This statement corresponds to the facts shown by the deep drilled wells of Connecticut, although in such waters there is a small change of temperature during the rise of the water to the surface.

[a] Movements of underground water: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, pp. 75–77.

CONTAMINATION.

From what has been stated above, it is evident that ground water does not exist in pools or cavities in the rock and is not stationary. It has a movement in a definite direction, which can be determined for any given place. A velocity as high as 100 feet in twenty-four hours has been measured, but the common rates, even in sand, are only from 2 to 50 feet a day. (See p. 47.) The fact of the movement is undisputed and has an important bearing on health, for disease germs may be carried by water wherever it travels. No kind of rock or soil is proof against the transmission of ground water containing pollution. Fuller [a] has shown that water may traverse several miles of crystalline rock and may carry contamination through that distance. In a settled community too much emphasis can not be placed on the necessity of locating wells in positions where they are not liable to infection. The only safe way is to treat ground water as if it were a surface stream. No one would use water from a river a short distance below points of contamination, and no one should use water from wells where the downward slope of a ground-water table is such that the water might carry infected material. (See pp. 171–172.)

[a] Fuller, M. L., Bull. Geol. Soc. America, vol. 16, 1905, p. 372.

CHAPTER IV.

GROUND WATER IN THE CRYSTALLINE ROCKS OF CONNECTICUT.

By E. E. Ellis.

INTRODUCTION.

The laws governing the occurrence of ground water in unconsolidated material and in porous sedimentary formations are now generally understood, but little has been written concerning the sources of supply for wells in the so-called crystalline rocks. The term "crystalline rocks" is used for those rocks whose component grains have crystallized into their present relative positions, in contrast with the sedimentary rocks, which were laid down under water and generally consist of fragments of older rocks mechanically arranged. Under the head of crystalline rocks two main types may be distinguished—(1) igneous rocks, such as granite, diabase, gabbro, etc., which were once in a molten condition and which crystallized and hardened on cooling; (2) metamorphic rocks, such as schists and gneisses, which were originally either sedimentary or igneous but have been altered by metamorphic processes to their present form.

Connecticut offers an exceptionally good field for an investigation of ground water in the crystalline rocks, as more than two-thirds of the State is underlain by rocks of this type (see fig. 11) and a large number of wells have been drilled in this area.

LITERATURE.

It seems necessary to dwell on the theoretical principles involved in the occurrence of ground water in crystalline rocks more largely in this paper than is customary in a report on underground water resources, because of the scarcity of previous information on these points. Accordingly a summary of the most important articles which have been written on such occurrences is here given. Many of these articles are contained in the discussions of the relation of circulating waters to ore deposits and to metamorphic changes. The principles involved, however, have been deduced for water circulation in general, both in rocks permeable because of their porosity and in rocks giving opportunity for circulation only through fracture planes; the latter type corresponds to the crystalline rocks under discussion. The theory as stated by Van Hise[a] considers that there

[a] Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904.

are two general zones of water circulation—a zone below the level of ground water, where all openings in the rocks are filled with water, and a zone above the level of ground water, where the openings are but partly filled. He considers the extreme possible depth of circulating waters to be about 10,000 meters, which is the limit at which open fractures may exist. The circulating waters are considered to enter the earth's crust at many points and as, owing to the force of gravity, they work downward, they tend to seek larger and larger channels, which offer less resistance to their flow, and finally to converge in some large channel and emerge at the surface at some point lower than that where they entered. Gravity is considered to be the primal force in producing this circulation. The chief objection to this theory has been the assumption of a saturated zone below a certain level. Similar theories have been less fully brought out by Daubrée, and by De Lapparent.

Certain general statements regarding the occurrence of water in crystalline rocks and the procuring of water from joint planes are given by M. L. Fuller.[a]

In a paper on the water resources of a crystalline area in New Hampshire and Maine, George Otis Smith[b] has discussed the manner of occurrence of water in these rocks. He considers that the movement of the water is confined to stratification partings, joint openings, and less continuous passages, the main circulation being along master joints which are nearly horizontal. The circulation is slow owing to the constricted nature of the openings, and the water supplying wells is contributed from distant areas and is confined largely to trunk channels. The occurrence of certain flowing wells is attributed to constriction and cementation in the upper portions of the fractures, giving opportunity for hydrostatic pressure.

J. A. Holmes[c] describes the occurrence of water supplies from the contact of fresh rock and the decomposed portion above in the crystalline rocks of North Carolina, but considers the undecomposed rock to be an uncertain source of supply.

The only published discussion of well supply in the crystalline areas of Connecticut is by H. E. Gregory,[d] who gives certain statistics regarding the wells in this area.

A number of records of wells drilled in crystalline rocks in New Jersey, Pennsylvania, New York, and Connecticut are given in the water reports of the New Jersey Geological Survey.

A. Daubrée,[e] in a treatise on subterranean waters, has paid particular attention to various types of fractures that offer passage to

[a] Occurrence of underground waters: Water-Supply Paper U. S. Geol. Survey No. 114, 1905, pp. 28–29, 39.

[b] Water resources of the Portsmouth-York region, New Hampshire and Maine: Water-Supply Paper U. S. Geol. Survey No. 145, 1905, pp. 120–128.

[c] Notes on the underground supplies of potable waters in the south Atlantic Piedmont plateau: Trans. Am. Inst. Min. Eng., vol. 25, 1896, pp. 936–947.

[d] Underground waters of Connecticut: Water-Supply Paper U. S. Geol. Survey No. 114, 1904, pp. 78, 79.

[e] Les eaux souterraines, 1887, pp. 150–157, 271–277.

water. In considering rock fractures in relation to circulating waters he distinguishes three classes—"leptoclases," or small discontinuous fractures such as occur in basaltic structure, dividing the rock into comparatively small fragments; "diaclases," characteristic of all rocks and dividing the rock into polyhedrons by their mutual intersections; and "paraclases," which represent such continuous fractures as faults. The diaclases or joints are considered as planes extending in many places more than 300 feet laterally, and a joint series may extend with the same mean orientation for many miles. Their vertical extent is variable. In discussing the occurrence of water in crystalline rocks Daubrée notes the irregularity of occurrence and the general feebleness of springs from such rocks. He then states that however unimportant the movements of water may be near the surface, water-bearing fractures are still less accessible with depth, because they are less numerous and have tighter walls, and cites the experience of engineers in piercing the St. Gothard tunnel as proof. He also describes a series of three lava flows near Catania, which have absorbed an entire river into their fractures.

Nordenskiöld[a] has described a series of wells sunk at seven localities in Sweden on islands of igneous rocks such as granite, diorite, etc. These wells all obtained fresh water at a depth of 100 to 120 feet, and he considers the supply to be derived from horizontal fractures caused by the daily variations in temperature. He considers the most favorable localities to be where vertical joints are lacking, but does not account for the origin of the fresh water.

DISTRIBUTION AND CHARACTER OF THE CRYSTALLINE ROCKS IN CONNECTICUT.

The general distribution of the crystalline rocks in Connecticut is shown on the map (fig. 11), where the State is seen to be divided into three sections, consisting of two areas of crystalline rock separated by an area of sandstone and trap which occupies a general depression between the higher crystalline rocks. The crystalline areas are well drained, although here and there lakes of glacial origin occur, and the stream waters contain unusually small amounts of mineral matter. The softness of the water has been an important factor in determining the location of many of the great woolen mills throughout the State.

ROCK TYPES.

The three types of crystalline rocks that cover the greater part of Connecticut beyond the limits of the central Triassic area are granite, gneiss, and schist, although near the western portion of the State there is a considerable area of dolomitic limestone largely changed to mar-

[a] Sur une nouvelle espèce de puits dans les roches granitiques de la Suède: Compt. Rend. Acad. Sci., vol. 120, 1895, pp. 857–859.

ble. There are also several areas of more or less schistose quartzite. Cutting these formations are many masses of pegmatite and a few dikes of diabase or trap rock, and in the central Triassic area the trap occurs both as dikes and as surface flows standing in high hills and ridges above the general central plain.

Granite.—There are many varieties of granite throughout the State, but they may all be distinguished by the characteristic granitic texture. The rock which throughout this discussion is considered as granite is in reality a granite gneiss—that is, a granite which has been subjected to metamorphism and has thereby acquired a gneissoid structure. The original granite nature is clearly evident and as gran-

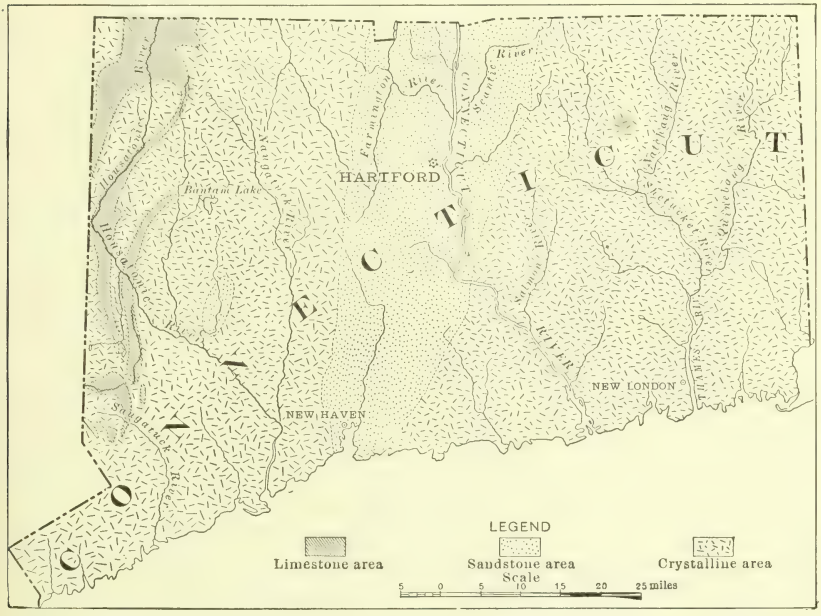


FIGURE 11.—Map showing areas of limestone, sandstone, and crystalline rock in Connecticut.

ite is a more popular name, this term is retained in the discussion, although on the map the designation granite gneiss is used.

The rock is composed mainly of grains of quartz, feldspar, and mica, which are of fairly uniform size and easily distinguishable from one another. The rock is massive and will split about as readily in one direction as in another, except in joint planes. Locally schistose and gneissose phases occur even in a typical granite, giving one direction of easy fracture in the plane of schistosity. The main granite area is in the southern portion of the State and extends along or near a large part of the shore line.

Along the coast from the New York state line to Bridgeport is an area of somewhat similar rock called granodiorite. This rock resem-

bles granite but contains a much larger proportion of the black mica (biotite). At many places in this area it is highly schistose and may be split much more readily in one plane than in others.

Gneiss.—The gneiss is a more variable rock than the granite, presenting very different characteristics even in adjacent areas and lacking the uniformity of texture of the granite. It may be distinguished by its banded or streaked appearance. It contains a large amount of feldspar and usually a considerable proportion of black mica or black amphibole, which, being present in greater amounts along certain lines than along others, gives the rock an appearance of alternating darker and lighter streaks. In some of the rock these streaks are developed into even bands from one-half inch to 3 feet in width, which continue for several hundred feet with variations of less than an inch in thickness. The most conspicuous area of gneiss is in the southeastern and eastern part of the State. Another large area consisting mainly of schist injected by granitic material occurs in the vicinity of Waterbury.

Schist.—Although schist usually contains a large amount of quartz and feldspar its most conspicuous constituent is mica, which on casual inspection appears to constitute the bulk of the rock. A careful examination will show that these mineral particles are much longer than they are wide and thick and that their longer axes lie in the same direction. This is the direction of schistosity or rock cleavage, and the rock splits along this plane much more readily than in any other direction. Wherever there is an exposure of schist the tendency of the rock to split along the plane of schistosity together with the high angles at which these planes usually stand gives a jagged and serrated appearance to the rock surface. The parting plane is usually rather uneven, but in certain types of schist it is very smooth and shows a shining surface in the sunlight. Schist of this type called phyllite, is too fine grained to distinguish the separate constituent particles and closely resembles slate, being in fact, intermediate between a slate and a schist. Certain of the chloritic schists of Connecticut assume a similar aspect. Though nearly all the Connecticut crystalline rocks are characterized by the presence of garnet, this mineral reaches its largest and best development in the schists.

The greatest development of the schists is beyond the western border of the Triassic area and in the area running from Middletown to the northeast corner of the State.

Quartzite schist.—There are several areas of an extremely quartzose schist in the northeastern and northwestern portions of the State. This rock is composed entirely of quartz grains and is supposed to represent a quartzite completely metamorphosed to a schist. In the western part of the State recementation appears to have taken place,

resulting in an extremely indurated rock more nearly resembling a true quartzite.

Pegmatite.—Traversing many of these rocks are dikes and irregular masses of pegmatite, which are white or very light in color and consist in great part of large crystals of white or pink feldspar with quartz and in places bunches of broad-leaved mica. This rock is usually called "feldspar" by drillers and quarrymen.

Trap rock.—The trap rock is familiar to nearly everyone, and is easily distinguished by its dark color and fine-grained and compact texture. It occurs in the crystallized rocks as intrusive masses or dikes of material which has been thrust into older rocks. The external appearance of these dikes in the highland areas is closely similar to that of the traps of the lowland, and in composition the two rocks are identical.

Limestone.—The limestone is softer than any of the other rocks considered; it may be readily scratched by a knife and will usually effervesce when acid is applied. It is ordinarily white or gray in color, and is the only rock considered in the present discussion which may be definitely classed as of sedimentary origin without careful study. It is usually dolomitic—that is, it contains a considerable proportion of magnesium carbonate and in many places has been metamorphosed to a genuine marble.

DRILLING PRODUCTS.

The marked characteristics of these rocks give equally characteristic products in drilling. In many places the drill will yield fragments that are large enough to show the general texture of the rocks. In others the drillings will all be in the form of rock dust. In general the granite drillings are even grained, with a large proportion of the white or pink minerals, quartz and feldspar, and the same character and color of material will be maintained for a number of feet. Gneiss gives a somewhat similar product but as a rule has a larger proportion of biotite (black mica) and the character of the drillings changes rapidly, usually every few inches. Schist is generally softer and more readily drilled than either granite or gneiss, and the drillings contain a conspicuous amount of mica which occurs in larger particles than the other minerals. As in granite, the drillings maintain a fairly uniform appearance. The phyllite is usually a hard rock to drill, owing to its fineness of grain and the nearly vertical position of its cleavage at many places. Trap rock is considered the most difficult rock to drill, because of its hardness; it is readily distinguished from the other types. Limestone drillings are ordinarily white, and may be tested by adding acid or strong vinegar, which will produce an effervescence, owing to the escape of carbon dioxide.

DRIFT.

Although in some places, particularly in the southern part of the State, the rocks above described are exposed at the surface, they are in large part covered with glacial deposits—till and stratified drift. The till occurs as a relatively thin layer over the rock surface both in valleys and on hills, and the valleys are filled with heavy deposits of stratified sand, gravel, and clay deposits resting upon the till and tending to form a flat valley floor. At many places the till has been eroded and the stratified deposits rest directly on the rock. The till deposits on the hills average about 15 feet in thickness, varying where present up to 60 feet or more; the valley deposits at many places are over 100 feet thick and average about 36 feet, although varying within very short distances owing to the irregularities of the underlying rock surface. These averages are made from the well records in the crystalline areas.

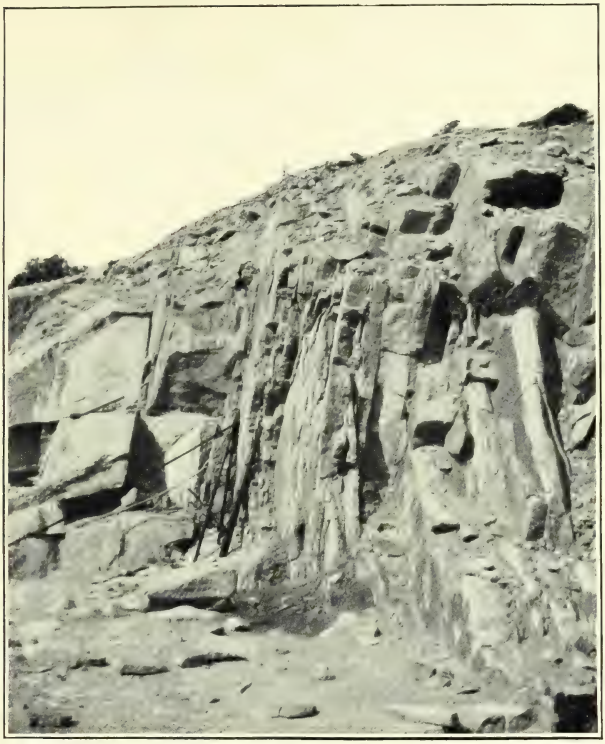
In general, therefore, the hills have a configuration corresponding rather closely to that of the underlying rock surface, the minor irregularities of which are masked by the overlying drift. On the other hand, the valley bottoms are flat and a decidedly different topography would be shown if the sand and gravel deposits were removed. The general relation of the glacial deposits to the underlying rock and to each other are indicated in figure 23.

CONDITIONS AFFECTING OCCURRENCE OF WATER IN CRYSTALLINE ROCKS.

INTRODUCTION.

The occurrence of water in crystalline rocks is necessarily unlike that in most kinds of water-bearing sedimentary rocks, owing to the great difference of texture in the two types. In unmetamorphosed sedimentary rocks the pore space is usually large, running above 20 per cent of the total volume in many sandstones and locally above 40 per cent. This means that such rocks will absorb an amount of water equal to one-fifth or even two-fifths of their entire volume. In the crystalline rocks there is little pore space between the constituent grains, which have crystallized into their present relative positions and therefore closely interlock with one another. Few of the granites have a porosity exceeding 1 per cent, and the average is 0.5 per cent or lower.[a] In gneissoid granites the proportion of pore space is about the same, and in slates it is less, averaging 0.45 per cent or lower. Although in many limestones the porosity runs above 10 per cent, their metamorphosed equivalents—the marbles—have a porosity about equal to that of granite.

[a] Buckley, E. R., Building and ornamental stones of Wisconsin: Bull. Wisconsin Geol. Survey No. 4, 1898, p. 374.



A. VERTICAL JOINTS IN GRANITE.

B. HORIZONTAL JOINTS IN GRANITE.

In such rocks as these, which absorb less than 0.5 per cent of their volume of water and contain less than 1 per cent of uniformly distributed pore space, the pores are mainly of subcapillary size and, though admitting water, allow little and exceedingly slow transmission. In many of the sedimentary rocks, on the other hand, the openings between the grains are of capillary or supercapillary size and give ready transmission to circulating waters. Therefore in the crystalline rocks the only circulation of water which has sufficient rapidity of movement to be of value as a source of well supply must be through joints and fractures developed subsequent to the crystallization. (See fig. 12.)

JOINTS.

A joint in rocks may be defined as an opening or fracture of great length and depth as compared with its width. Joints are produced by mechanical action which causes the rock to break into more or less regular blocks after it has hardened. They are usually attributed to some dynamic force that brings about movements in the earth's crust. They are ordinarily called seams or cracks by drillers.

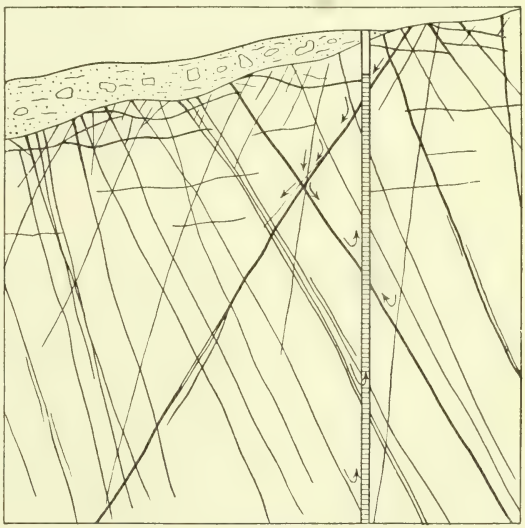


FIGURE 12.—Diagram illustrating the manner in which a well obtains water by cutting joints.

Vertical joints.—The most common type of joints comprises those in planes approximating a vertical position. (See Pl. I, *A*.) Though there are many joints within 2° or 3° of verticality, the greater number deviate considerably from this position. A large number of measurements were made on the inclination of this type of joint in the crystalline areas of Connecticut, the average inclination of a series at any exposure being taken rather than a number of measurements on separate joints at the same exposure. The mean inclination, as shown by 75 observations, was 74° from the horizontal. In only four observations did the inclination run below 40°, in 14 it was between 40° and 70°, in 17 between 70° and 80°, and in 40 between 80° and 90°. It is evident that in the Connecticut crystalline rocks the main jointing is between 70° and 90°. In several of the places where lower inclinations were observed the jointing was parallel to some structure plane in the rock.

Horizontal joints.—In many of the rocks there is another set of joints which are very distinct from those of the vertical type, both in their degree of inclination and in their general nature. This set occupies an approximately horizontal position, in few places pitching more than 20°, and as a rule much less than this. (See Pl. I, *B*.) In general this joint structure follows the surface configuration of the rock, but here and there it pitches at a low angle in an opposite direction to the slope of the hillside. In the most extreme cases of deviation from a horizontal position this jointing was found to be approximately parallel to planes of schistosity in the rock. This is well shown in the lower of the two gneissoid granite quarries near Maromas.

In the further discussion of jointing, the names vertical jointing and horizontal jointing will be used for these two main types.

Relation of rock type to jointing.—Both vertical and horizontal jointing are present in all the crystalline rocks, but occur in greatly varying degrees of development in the differing types. The horizontal joints are typically developed in the massive granites, where they are commonly very regular. They form the most striking feature of quarries in such rocks and constitute the plane of separation called "bedding" by the quarry men. In the gneissoid granites these joints are developed equally well, but their direction is determined by the gneissoid structure in some places where that lies at a low angle to the horizontal.

In the typical gneisses the joints are irregular and uncertain and occur only near the surface; in the schists they are usually lacking, although here and there irregular and discontinuous fractures may be seen running in a nearly horizontal plane. Where such horizontal fractures occur in schists they are usually near the surface and very open.

The vertical jointing is not confined to any particular rock type, but is developed throughout all consolidated formations, both sedimentary and igneous. The degree and nature of the development, however, vary not only with varying rock types, but also to a great extent in rocks of the same type in different localities. This difference of development at the contact of rocks of two distinct types may consist of a mere tightening or closing of the joint on passing into the second rock, or of a difference in the number of the joints in the two rocks, indicating that some joints have stopped at the contact lines. Numerous instances of the former difference have been noted in the studies of ore bodies, and a good example on a small scale, typifying both differences, may be seen in the railroad cut just west of the station at West Haven, Conn. Here lenses and streaks of extremely schistose and slaty rock occur with similar layers of compact diabase several feet in thickness. The diabase is completely traversed by

A. JOINTS IN SCHIST AND METAMORPHOSED DIABASE.

B. JOINTED AND FISSILE SCHIST.

joints and seams, some of which stop abruptly at the contact with the schistose rock, while those which continue across the schist are relatively tight. A similar occurrence on a larger scale may be seen on the north bank of Housatonic River, 3 miles above Derby, where a schist lies above a heavy pegmatite. It is impossible with present evidence to say what will be the rule in this respect at the contact of a schist and a granitoid rock, but it seems probable that in most such places the joints will become tighter and less numerous in passing from a granitoid to a schistose rock. (See Pl. II, *A*, *B*.)

Joint direction.—Any individual joint maintains a fairly constant direction with a few small curves, and here and there the same directions of prominent jointing will remain fairly constant over a considerable area, as shown by the observations of Hobbs[a] in the Pomperaug Valley, where he found four major directions of jointing. Where there is a particularly well-developed joint set the series may maintain the same general direction for long distances.

In a series of observations throughout the crystalline areas of the State it was found by the writer that a much larger proportion of joint systems ran in a northwest–southeast direction than in one northeast and southwest. However, for particular localities the direction of jointing can be determined only by local observations.

Structure planes.—Of secondary importance to the joints as regards water supply is the presence of structure planes, such as schistosity and gneissoid banding in the rocks. In rocks exhibiting these features there has been more or less fracturing parallel to the structure planes, which have an average inclination much lower than the joints. The planes of schistosity dip at all angles, but for any single formation there is usually some dip which is more constant than others. Observations on these formational dips in Connecticut show them to be quite as commonly below 45° from the horizontal as above that angle, whereas, as previously shown, most of the joints, exclusive of the horizontal joints, have greater dips than 75°.

The fracturing parallel to the schistosity may consist of rather widely spaced and relatively open fractures or of small discontinuous breaks an inch or less apart, producing a structure known as fissility. Whatever the nature of these fractures, they will average a lower inclination than joints, although in some rocks, as in the chlorite schist and phyllite west of New Haven, they are nearly vertical.

Variation in jointing.—In the schists and similar rocks, with a marked schistose structure, such as the schistose granodiorite along the coast east of Greenwich, there is usually one direction or system of jointing that is more prominent than any other. This main system

[a] Hobbs, W. H., The Newark system of the Pomperaug Valley, Connecticut: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, pp. 7–162.

is, as a rule, accompanied by a wider spaced and less well developed series of joints intersecting the main series at high angles. In the schistose granodiorite the jointing is well developed, rather closely spaced, and very uniform in direction. In the schists the joints maintain a fairly uniform trend, but are commonly very tight, and in much of the rock die out within short distances. In most exposures one or two distinct series of joints can be distinguished, and many small irregular fractures connecting the main joints occur near the surface, but disappear at relatively shallow depths.

In the granitoid rocks the vertical joints are generally more open and continuous than those in the schistose rocks, but usually lack their characteristic regularity of arrangement in series and are ordinarily more widely spaced. Although in many of these rocks there is one set of joints with a general parallel direction, even in the joints which may be classed in the same series there may be a variation of 10° to 20° in direction, and other vertical joints may intersect these with no regularity of arrangement with reference to each other. This is the usual occurrence of jointing in the Connecticut crystalline rocks of this class, but in certain places two, three, or even four distinct sets of joints may be distinguished.

The limestones of the State are even more irregularly fractured than the granites and the fracturing is usually so close as to prevent the use of the rock as building stone. Joints cut these rocks at all angles, and the general shattering has produced more open space than in any other type of rock which might be classed as crystalline.

No general conclusions on the occurrence of vertical joints in the crystalline areas of Connecticut will hold for every portion, as there is great variation in their occurrence within short distances, even in the same formation. On the other hand, the horizontal joints have a very uniform mode of occurrence for all the granitoid rocks. They are approximately parallel to the rock surface, except where influenced by local factors such as structure planes, and are spaced at fairly uniform distances from one another. They are everywhere curved or wavy and intersect one another at varying intervals, dividing the rocks into a series of approximately horizontal wedges with curved faces. The principal variation is in the closeness of these intersections. In some places the horizontal joints intersect one another every 20 or 30 feet; in others they run parallel to one another for 100 feet or more. In general the horizontal jointing is more regular, though not necessarily better developed, where the amount of vertical jointing is small. A good example of this may be seen in the gneissoid granite quarry at Monson, Mass., where there is an excellent parallel horizontal jointing but vertical joints are almost lacking and except at the immediate surface are filled with vein material.

FAULTS.

Faults may be considered as extreme types of joints in which there has been movement of one wall of the joint plane past the other. The work of Hobbs, Davis, and others has shown that there has been a considerable amount of faulting in Connecticut, and it is not uncommon to find strongly marked shear zones, indicating slipping in the crystalline rocks. These are rather rare phenomena, however, and are seldom encountered in well drilling; accordingly they will be treated simply as special cases of jointing. They are probably very important as channels for spring waters, although it is extremely difficult and generally impossible to ascribe any particular spring to a fault plane.

CIRCULATION AND STORAGE OF WATER.

The circulation of water in the crystalline rocks, being confined to openings of the sort discussed in the foregoing pages—that is, those having great length as compared with their thickness—is necessarily limited by the abundance of these planes of parting, by their degree of opening, and by their intersection of one another; and there are many modifying factors, such as local entrance conditions for surface waters, local textural variations in the rock, intrusions and inclusions of other rocks, and the restraining effect of overlying glacial drift.

INFLUENCE OF JOINTS AND OTHER OPENINGS.

Spacing of vertical joints.—The vertical joints, which are the important water carriers, have no regularity of spacing even in the same rock. These joints are much more closely spaced in natural outcrops, owing to the influence of weathering, and in railroad cuts where there has been heavy blasting than in quarries where the natural conditions prevailing in the rock below the surface are exhibited. In such natural exposures the spacing of joints was found to vary from a fraction of an inch up to 200 feet or more. The extremely close jointing occurs only in sheeted or shear zones which vary from a few inches to 2 feet in width, and these sheeted zones are a considerable distance from one another. Instances of such close sheeting as to give a spacing of 1 inch are exceptional, and are found in relatively few exposures. The same general occurrence on a larger scale, however, is typical of vertical jointing. In every quarry observed in Connecticut where jointing is developed over a considerable area the joints were found to be much more closely spaced at certain points than at others, constituting a series of zones of close jointing separated by intervals in which the distances between joints are much greater. These zones of close jointing vary from 1 foot to 15 feet in width and the joints making up the sheeted areas are spaced from 3 inches to

2 feet apart. Purington [a] describes a similar but more regular occurrence in a Colorado mine where, along the side of a drift, fissures 30 feet apart become nearer and nearer together until they are only 3 or 4 inches apart, forming a sheeted zone, beyond which the intervals gradually increase.

A number of observations on joint series in the Connecticut crystalline rocks indicate that at the places where jointing is well developed the average spacing is between 3 and 7 feet. It is very difficult to form an estimate of the average spacing for all rocks, however, for in some localities, as in the quarries at Monson, Mass., and Sterling, Conn., there are exposures of several acres where the rock has been quarried, and not more than three or four open joints can be distinguished in the entire quarry, giving a spacing of at least 100 feet. Here and there older joints may be distinguished which have been filled with vein material, but these can yield no water under present conditions.

If it were supposed that all the vertical joints were placed in parallel planes, both major and minor series, it is probable that the average spacing would not be less than 7 feet to a depth of 50 feet from the surface. The average spacing between vertical joints of the same series for the crystalline rocks, exclusive of trap and limestone, is more than 10 feet for this same zone of 50 feet from the surface, as shown by field observations, and the study of well records indicates that this is not far from the average spacing for all joints to a depth of 100 feet.

Spacing of horizontal joints.—The horizontal joints present much greater regularity of spacing than the vertical joints. They are apparently surface phenomena and diminish in number rapidly with increasing depth; it is probable that they do not exist at a depth of 200 feet. For the first 20 feet below the surface these horizontal joints average 1 foot apart, for the next 30 feet they average between 4 and 7 feet, and for the next 50 feet they are much more widely spaced, being from 6 to 30 feet or more apart.

Continuity of horizontal joints.—The length of individual horizontal joints rarely exceeds 150 feet, but owing to their intersection of one another they may constitute a continuous opening several hundred feet long, which would have the form of a curved sheet approximately parallel to the hill slope, each lower sheet having less curvature than the one above. They are probably better developed on the hills than in the valleys, as the pitch of the joints is usually less than the slope of the surface, which consequently cuts across the joints. Moreover, as they are more widely spaced with depth the horizontal joints that cross the valleys are widely spaced.

[a] Purington, C. W., Preliminary report on the mining industries of the Telluride quadrangle, Colorado: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 765–769.

Continuity of vertical joints.—There are two directions in which vertical joints may have great length—vertically, or along their dip, and in the direction in which they cut the surface. No mathematical relation between these two directions has been determined, but it has been assumed in the study of ore deposits that a fracture will have about as great extent along the dip plane as along the strike plane.[a] The degree of continuity is very uncertain owing to the difficulty of direct observation on either the entire length or the depth of any joint, and to the fact that a joint may exist with its two sides so closely pressed together that the fracture is not apparent to the naked eye. It is certain that some joints are far more continuous than others and that many die out within very short distances both vertically and laterally. Faults have the greatest continuity and may extend for several miles across the country, or even for tens of miles. The sheeted zones of closed jointing are probably almost as continuous as faults, and their dimensions should be measured in hundreds of feet. Where there is a well-defined series of parallel joints the prominent joints may extend for several hundred feet, while the minor intersecting joints will be much shorter.

Fissility and schistosity openings.—The circulation of water as determined by structure planes has not been discussed up to this point because the evidence is not as clear as in the case of joints. Although it is probable that the absorptive capacity of a schist would be greater than that of a slate, owing to the larger size of the grains, the porosity would still be too small to allow any circulation in the pores. In a crumpled schist there are probably small openings between the folded laminæ, but these must be discontinuous and would not allow sufficiently rapid circulation for well supply. However, there are nearly everywhere fractures of considerable extent parallel to the schistosity, but with much less regularity of occurrence than the joint planes in the same rock. These fractures also are much less continuous than joints and die out within short distances.

In such discontinuous fractures the circulation would be comparatively slow, but sufficient for well supply. Small springs issue from such fractures at many places, as along the east bank of Connecticut River above Hadlyme Landing. These fractures are much more numerous near the surface, particularly where the dip of the schistosity is in a low plane, and become tighter and less abundant with increasing depth.

Intersection of fractures.—It has been shown that the main circulation of water available for well supplies in crystalline rocks is along jointing planes, and it will be shown later that some joints carry a

[a] Ransome, F. L., Economic geology of the Silverton quadrangle, Colorado: Bull. U. S. Geol. Survey No. 182, 1901, pp. 61, 62.

greater amount of circulating water than others. It is evident that the intersection of joints with one another is a very important factor in determining the degree and direction of the underground-water circulation.

The manner of occurrence of joints indicates that such intersection may be found in every possible direction, but that there will be much better connection in some of them than in others. In the granitoid rocks, where the vertical joints have little regularity of arrangement and therefore intersect one another at many points, and where the horizontal joints are nearly universal, there is a thorough connection between the various fractures of the upper zone in which the horizontal joints occur. In the schists and schistose gneisses, in which the joints are usually more regular in arrangement and in which the horizontal joints are poorly developed, the connection between the various joints is less complete. In these schistose types, as in the granitoid rocks, there are invariably cross joints connecting the main systems, but they are commonly considerable distances apart and are tighter than the main joints, so that the opportunity for lateral transmission of water from one joint to another parallel joint is less than for longitudinal transmission along the main joints. The connection of the small and discontinuous fractures in the planes of schistosity is much poorer than that of the joints.

Opening of joints.—The degree of opening between the walls of joints is exceedingly variable and very difficult to measure. At the immediate surface many joints have an opening of half an inch to 2 inches, or even much greater. This wide opening is due to various weathering and mechanical agencies, which act only near the surface, and consequently is not found at depths below which these agents act. In an artificial cut, such as a quarry wall, many of the joints which may be open half an inch at the surface are too tight to admit a knife blade at a depth of 25 feet.

The joints at 30 feet below the surface may have only one-twentieth the opening that they have at the surface, but the same proportionate tightening will not continue at lower depths, although it is certain that the greater the depth the greater must be the tendency of joints to close, owing to increased pressure and to the smaller opportunity for lateral expansion below the level of minor topographic relief.

The closing with increasing depth is, of course, a measure of the vertical continuity of the joint, and it seems very probable that there is a direct relation between vertical and longitudinal continuity. Accordingly there is a great variation in the depths at which different joints close; the smaller joints close at moderate depths, but the larger joints continue to varying greater depths according to their importance.

If the above statement holds true, the closing of the joints produces not only a tightening with increasing depth, but also a decrease in number or a widening of the space between joints. This principle applied to the vertical joints is closely analogous to the tightening and increase of spacing of the horizontal joints with increasing depth, which may be observed at nearly any granite quarry, although the causes producing the two types may be different.

The application of this principle in the drilling of wells is of the utmost importance, as it is frequently asserted that water can always be obtained by going deep enough, whereas the deeper the well the less the chance of striking fractures, which are the only passages permitting water transmission in crystalline rocks. It is evident that, owing to the closing with depth, there will be a much greater circulation in the upper half than in the lower half of any individual joint.

Though many of the joint openings are supercapillary in size, most of them are probably of large capillary size. The upper limit of capillary sheet openings is about one one-hundredth of an inch, which gives an opening of appreciable size, but in a freshly quarried wall the greater proportion of the joints have manifestly less width than this. A rough estimate of the degree of opening of joints may be made from the yield of wells in the crystalline rocks, which average about 17 gallons a minute, although the greater number give less than 15 gallons a minute. The average well intersects between three and four joints, and this number of saturated joints would supply much more than the average yield of the wells if the openings were appreciably larger than capillary size. These openings, however, must be toward the upper limit of capillarity in order to yield 10 to 15 gallons a minute. Some wells undoubtedly pass through openings of much greater width than 0.01 inch, and nearly every well driller can cite several instances when his drilling tools have suddenly dropped several inches. Although the driller usually considers the sudden fall of the tools to indicate an open crevice, the probability is that no actual open space exists, but that a fracture has been encountered in which decomposition has softened the rock walls to such an extent that the material offers little or no resistance to the heavy drill. Nearly every quarry in the crystalline areas of Connecticut gives examples of such decomposed strips bordering joints, but such an occurrence as an opening wider than a fraction of an inch in crystalline rocks, except at the immediate surface, is practically unknown to quarrymen.

It is probable that openings of considerable size occur along fault planes, but faults are relatively few as compared with joints, and there is small chance of a drill hole penetrating them. Some of the wells of larger capacity may derive their water from such fault

openings, although more probably it comes from a closely sheeted zone.

Number of contributory joints.—The number of fractures supplying water to a single well varies greatly in different wells. In some wells the greater part of the water appears to come from a single opening; in others the water comes in slowly from a large number of openings. In the average well there are from one to four horizons at which the principal supplies of water are obtained, although the yield from one of them is usually greater than that from all the others together. This is particularly true of the wells from 200 to 300 feet deep, in which the principal source is usually very close to the bottom of the well.

From the character of the fractures in the varying rocks it seems probable that the wells in gneiss and the deeper wells in granite derive their main supplies from one or two comparatively large openings, but that in the more schistose rocks the fractures contributing water are more numerous but less open. In the upper portions of the wells in granite the horizontal joints contribute a series of small supplies below the point where the water level is struck.

If an average inclination of 70° from the horizontal and an average spacing of 10 feet is assumed for the vertical joints for the upper 200 feet of rock, each well 200 feet in depth would intersect seven joints. This is probably not far from the average for all the wells, exclusive of the small and discontinuous fractures near the surface. Below 200 feet the average number of joints intersected would be somewhat decreased for the next 100 feet and greatly decreased at lower depths than 300 feet. It is evident that in some localities the joints are much more closely spaced than in others, that locally they are highly inclined and elsewhere lie at low angles, and that all these factors modify the number of fractures which a well intersects.

WATER LEVEL.

If the fractures were all equally open and had complete connection with one another, there would be a zone of saturation in the crystalline rocks and the upper surface or water table of this saturated zone would follow rather closely the shape of the rock surface, as in sand or other homogeneous porous material. Under such conditions the water in adjacent wells should rise to the same level. In homogeneous sands the upper limit of the saturated zone is called the water table. In describing the occurrence of water in joints the term "water level" will be used to indicate the upper limit of the saturated portions of the joints.

Observation shows that the fractures are of greatly varying degree of opening, and that although most of them are connected with one another in some way the connection is much better in some places

than in others. It is to be expected that under such conditions water will rise to different heights, even in joints which are close together, when there is no connection or very poor connection between them. As a typical instance of such variation may be cited the wells drilled for the Fitch Home for Soldiers at Noroton Heights, Conn. One well was drilled to a depth of 425 feet in the bottom of a small valley, resulting in a flow of 4 gallons a minute that rose more than 7 feet above the surface. A second well was drilled 130 feet away and at an elevation only 4 feet higher, to a depth of 503 feet, and in this well the water rose only within 15 feet of the surface. Both wells passed through about 12 feet of hardpan. The difference of pressure head in these wells, only 130 feet apart but evidently deriving their water from different fractures, is therefore more than 18 feet. Both these wells give heavy yields on pumping and the pumping of the second well does not affect the flowing well, although it lowers the level of the water in an old drilled well higher on the hillside. Similar occurrences have been noted at other places, even in wells less than 100 feet deep.

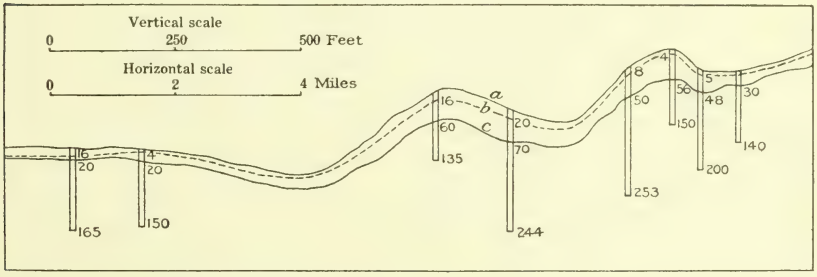


FIGURE 13.—Sketch showing relation of water level to topography. *a*, Surface of ground; *b*, line indicating height at which water stands in wells; *c*, rock surface.

Although there are local irregularities in the water level in the crystalline rocks, such as that just described, the general surface of the saturated zone still follows the topography, as is shown by the heights at which the water stands in the various wells. (See fig. 13.) The following table indicates the relation of the level at which the water stands in the wells to the surface of the rock:

Relation of water level in wells to surface of rock.

Position.	Number of wells averaged.	Percentage with water level—		
		Below rock surface.	Above rock surface.	Even with rock surface.
Hills	42	61.9	26.2	11.9
Valleys	24	12.5	87.5	0
Slopes	35	48.5	40.0	11.5

It is thus evident that on the hills the water tends to stand below the rock surface, but that in the valleys it is under sufficient hydrostatic head to rise above the rock surface and under favorable conditions to cause flowing wells.

At many places on the hills the tendency of the water level in the crystalline rocks to stand lower than the rock surface gives rise to an unsaturated zone immediately below the drift, although the lower portion of the drift itself may be completely saturated and furnish excellent supplies for comparatively shallow dug wells of large diameter. The existence of such an unsaturated belt is believed to be due to the facts that the movement of water in certain places is more rapid through the upper fractured portion of the rock where the joints are open than through the relatively small capillary openings of the drift and that the water, having opportunity to escape from the rock crevices at some point lower than the entering point, is carried away down to a certain level faster than it is furnished. In some localities, however, where the fractures do not allow escape at lower levels, the water table of the drift and of the rock may be the same; that is, in wells deriving water from rock seams the water may rise to the same level as in open wells in the drift above. However, owing to the generally rapid movement in fracture planes the general water level tends to approach a flatter plane in crystalline rocks than in porous materials like sand, where there is greater frictional resistance to water flow and where the effect of capillary flow is greater.

The term "water level," as used in reference to the depth below the surface at which water stands in the openings of crystalline rocks, in its broad sense, implies a surface with much smaller differences of elevation than the water table of a sandstone area having similar topographic relief, but with much greater minor irregularity, owing to the great variation in the water channels. The larger fractures extending for long distances usually have some outlet to the surface, but in many of the smaller joints the water passes from one joint to another with no surface outlet. The fast flow in the larger joints lowers the level of the water in these and connected joints below that in neighboring unconnected joints having poorer outlets. Even in a connected series the water level will have different heights in joints of varying opening, owing to the faster flow in the more open joints, where friction is less.

DIRECTION OF CIRCULATION.

The movement of water entering any joint above the point where it is saturated with water will be mainly vertical along the dip or inclination of the joint. The circulation below the water level in any joint is both vertical and lateral. The lateral motion, along the

strike of the joint, predominates, owing to the fact that the length of the outlet or outlets for any particular joint is much smaller than the total length of the joint. Any connected series of joints there will manifestly have a very complex circulation, but the main circulation will be toward and along the fractures having the largest openings and the nearest outlets, and in these fractures the general movement will be in the direction in which the land slopes.

DECOMPOSITION AS A MEASURE OF CIRCULATION.

The relative importance of various joints in the water circulation is indicated by the decomposing effect of the water on the walls of the fracture planes. The oxidizing surface waters carrying carbon dioxide and organic acids naturally react on the minerals in the rock walls, the action being indicated in some places by a mere reddish-brown staining of the joint sides and here and there by a breaking down of the mineral particles, giving rise to a disintegrated border along the joint plane. There is a great difference in the amount of this weathering, even in joints which may be adjacent members of the same series, indicating that some joints are heavier water carriers than others of the same age, probably owing to greater opening and in some of them to better entrance conditions. The areas of greatest decomposition are along the sheeted zones, and next along the most continuous vertical joints, and in these fractures the weathering extends down to the limit of observation, with no apparent change. In the minor joints the weathering effects are less conspicuous and usually appear to the observer as mere discolorations, extending from half an inch to 3 inches or more on each side of the joint plane and becoming less marked with increasing depth.

As a rule the horizontal joints of the granitoid rocks show less weathering than the minor vertical joints. Though usually discolored and weathered near the surface, the walls of these joints are commonly unaltered at a depth of 20 feet. However, where the horizontal joints are cut by a prominent weathered vertical joint, the weathering effect extends along the adjacent horizontal joints to a very marked degree, diminishing in amount with increasing distance from the vertical joint. This feature is well shown in the granite gneiss quarry of the Rhode Island Brown Stone Company, 1½ miles west of the railway station at Oneco, Conn. At this quarry a heavy discoloration extends along the flat joints for a distance of 25 feet from a vertical joint, gradually diminishing in intensity. Occasionally a flat joint is found which is weathered throughout its exposed length. (See Pl. III, *B*.)

In the sheeted zones it is common to find a strip of disintegrated material from 1 to 6 inches in thickness and in the large single vertical joints similar but narrower bands of disintegrated rock occur.

Through such material as this a large amount of water can pass with comparative ease.

If the degree of decomposition along joint planes is taken as a criterion of the amount of circulation along the joints it would appear that the circulation is mainly along the large vertical joints, next along the minor vertical joints, and in small amounts along the horizontal joints. Although this statement is probably true as to the proportionate amounts of circulation it does not mean that the unweathered vertical or horizontal joints are dry. The probability is that the lower horizontal joints are saturated with water, but that owing to the relatively flat planes in which they lie and their tendency to tighten at their intersection with one another, the water has a very feeble circulation.

The horizontal joints are probably much younger than the vertical joints and weathering has had less time in which to act, but the fact that some are weathered more than others indicates that even in these joints, which are manifestly of the same age, some offer better conditions than others for water circulation.

STORAGE OF WATER.

The wells in the crystalline area of Connecticut are remarkably constant, showing little variation in yield or depth of water, either annually or through a period of years. In some the yield has increased since the well was drilled and in a few it has decreased, but most of the wells have shown no appreciable change. The level to which the water rises in the wells shows nearly as great constancy as the yield, although in the shallower wells the water level varies somewhat with seasonal variations in rainfall, and in some of the deeper wells a lowering of water level has been noticed in unusually dry years. These fluctuations are most conspicuous in wells of small yield. In nearly all wells the water level is lowered to a greater or less extent on pumping, until by this lowering a sufficient increase of head is obtained to give an increased rapidity of flow, which will furnish a yield equal to that pumped out. When the pump is stopped the water will gradually, or in some wells very rapidly, rise again to its normal level. Minor fluctuations are probably more common than is reported, as changes in level are not readily noticed in covered wells. However, it is evident that there must be a very constant supply of underground water to maintain so constant a level in the wells.

The total average yearly rainfall in Connecticut is 46.89 inches, rather uniformly distributed throughout the year, and this uniformity of precipitation will, under natural conditions, with no artificial removal of water, give a fairly constant level for ground water in the rocks. If 25 per cent of this amount of rainfall is

assumed to be absorbed by the rocks—undoubtedly a considerably higher percentage than is actually absorbed—the total amount absorbed by an area of rock 100 feet square is 9,768 cubic feet, or 73,260 gallons. A well pumping 15 gallons a minute, which is about the average yield of wells in the Connecticut crystalline rocks, would draw out this amount in 81.4 hours. A well of this capacity pumping for 300 days during the year for one hour a day would withdraw an amount of water equal to 25 per cent of all the water falling on an area within a radius of 108 feet around the well. Probably 10 per cent of the precipitation more nearly represents the proportion absorbed by the rock than 25 per cent, and if so a well pumping at the rate above indicated would draw all the water on an area more than twice as great. When it is considered that some wells are pumped at the rate of 30 gallons a minute for ten hours a day throughout the year, it is evident that a single well may drain a very large area of all the water it absorbs.

With an average spacing for all fractures of 5 feet and an average opening of 0.01 inch, the saturated fractures in 1,000,000 cubic feet of rock, equivalent to a depth of 100 feet for a surface area 100 feet square, would hold 833 cubic feet of water, which a well with a capacity of 15 gallons a minute could pump out in seven hours if there were no renewal of the supply.

These figures are sufficient to indicate that the area contributing to any one well must be very large to maintain a constant level for the water in the well. Owing to the shape of joints and the manner in which they intersect one another this contributing area will be in the form of a number of long and comparatively narrow intersecting belts, and the well will draw water from very long distances. Wells on islands surrounded by salt water have been successful in obtaining supplies of fresh water, but they are usually moderate in yield and frequently somewhat contaminated by salt water, so that as a general rule fresh water obtained in these locations consists of that which has fallen on the island itself. Fuller,[a] however, cites a well on Fishers Island, 3 miles from the Connecticut coast, that penetrated 281 feet of unconsolidated gravel, sand, and clay in which salt water was found, and obtained fresh water in the crystalline rock below. No outcrops of crystalline rock occur on this island, and it seems clear that the fresh water must have come through the joint openings from the mainland 3 miles away. The water is evidently held in the rock openings by the restraining covering of clay above the rock.

As the head in all the wells is fairly constant, it is evident that the yield in any well is proportional to the number and opening of the fractures contributing water. As the heaviest yields are derived from the most open joints, and as these joints are the most continuous

[a] Fuller, M. L., Geology of Fishers Island: Bull. Geol. Soc. America, vol. 16, 1905, p. 372.

(see pp. 66–67), the following relation holds: The yield of water from a joint is proportional to its continuity, which depends partly on the number of intersecting joints and which consequently determines the area contributing to the wells. If this relation is true, and the yield is proportional to the contributing area, it follows that there will be no permanent change of head in the well until the amount withdrawn by the well is greater than the annual absorption of rainfall throughout the contributing area. This statement may be made in another way: When a small amount of water is pumped from a well the contributing area is small, but as larger amounts are pumped the contributing area is increased and the more remote connecting joints give their contribution to adjust the difference of level caused by the tendency toward depressions of the water level in the immediate vicinity of the well. Owing to frictional resistance to flow there will, of course, be some depression at this point, but it is probably relatively small. When the amount withdrawn by the well annually is greater than the amount annually absorbed by the contributing area the water level in each connecting joint is lowered and a permanent lowering of the water level results. As any lowering of the water level means a loss of head for the well, and as the head determines the rapidity of flow into the well, it is evident that when the water level is lowered the yield of the well will immediately decrease.

TABULATED WELL RECORDS.

The following tables, with the notes succeeding them, comprise the information obtained regarding the wells in the crystalline rocks. Logs of four of these wells are shown graphically in figure 14.

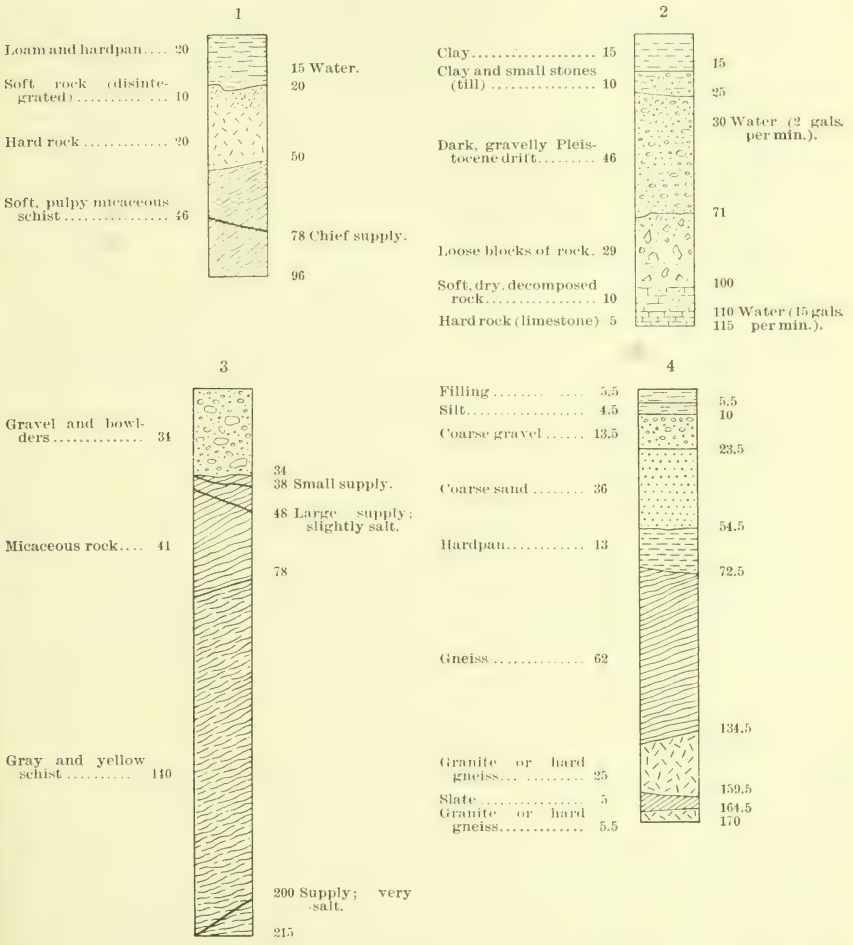


FIGURE 14.—Logs of wells in crystalline rocks. 1, Well of Thomas Fogarty, Ansonia; data furnished by C. F. Underwood. 2, Well of Miss E. O. Wheeler, Sharon; data furnished by A. J. Corcoran. 3, Well of Atlantic Starch Works, Westport. 4, Well of Sidney Blumenthal Company, Shelton; data furnished by the company.

Records of wells in crystalline rocks of Connecticut.

No.[a]	Town.	Locality.	Owner.	Topographic position.	Depth to rock.	Depth of rock.	Depth of well.	Depth of principal source.	Depth to water.	Variation of water level.	Yield per minute.	Diameter.	Temperature.	Quality.	Use.	Rock in which well is drilled.	Cost per foot.
					Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*		*Galls.*	*In.*	*° F.*				
1	Ansonia		Ansonia O. and C. Co.	Valley plain			209	209	20		16	8			Bleaching	Granite or granodiorite.	$5.00
*2	do		Thos. Fogarty	Hill	20	76	96	78	15		20	7		Med. hard.	General	do	4.50
3	do	Woodbridge Hill.	Mrs. Gilbert	do	10	90	100				Small.					Phyllite	
4	Barkhamsted		C. H. Tiffany	do			15	14½	6	Seasonal to 0.		33	45	Soft	Domestic	Schist or gneiss.	
5	Bethany		Arthur Doolittle				25	20	12		[b] 1,000			do		Slate	3.00
6	do		Albert Hosely	Slope			68			Seasonal	3	6		do	Domestic, stock.	Granodiorite.	
*7	do		H. F. Peck	Ridge	14	36½	50½	50½	16	do	3	6	48	Hard	Domestic	do	
8	Branford	Stony Creek	E. H. Coe	Shore, elevation 8 feet.			20		7	do					do	Granite	
9	do	do	Jas. S. Elton	Island	2	148	150			Pumps dry	[b] 250					do	
*10	do		J. C. Anderson	Island, elevation 6 feet.	2½	92	94½		10		Good.					Gneiss	
11	do	Short Beach	J. D. Welch	Slope, elevation 20 feet.	13	87	100	94	13	Constant	6	6		Hard	Stock, lawn	Gneissoid	5.00
12	Bridgeport		Hartman Brewing Co.	Valley plain	90	165	255		35			10	51	do	Brewing, condensing, washing.	Schist or granodiorite.	
13	do		do	do	11½	40	15½		15	Constant	35	6	51	Med	Brewing, washing, boiler.	do	4.00
14	do		A. Städtler	Hill	8	69	77	80	30	do	15	6		do	Drinking	do	6.50
15	do		Naugatuck Valley Ice Co.	Valley plain	42	648	690	120	18		8	8	52	Hard	Condensing.	Granodiorite.	
16	do		do	do	42	108	150				0			do	do	do	
17	do		do	do	42	8	50				10			do	do		
*18	Bristol		New Departure Mfg. Co.	Valley	50	265	315	75–150	12	Pumping lowers to 80 feet.	20	8.6	54	Soft	Boilers	Granite	
19	Brooklyn		Church of Sacred Heart.	Slope			106	106	28		12	6		Hard	Drinking, boiler.	Gneiss	3.00
20	Canaan	Falls Village	Dwight E. Dean		50	105	155		50	Constant	10	5		Med	Domestic	Limestone	2.00

21	Chatham	EastHampton.	Lake View Cemetery Assoc.	Hill	8	27	35	35		Seasonal	Small.			Hard	Watering	Schist or granite.	
22	do	do	Mrs. S. B. Childs.	do	13	162	175	174	2	Slight seasonal.		60		Med. soft.	Domestic	do	5.00
23	do	do	N. N. Hill		6	48	54		4		3+	6		Hard	General	do	5.00
24	do	do	D. A. Rich	Slope	6½	42	48½		7		½	6		Soft	Domestic	do	5.00
25	do	do	Chas. Lucas	do			38	35						do	do	do	
26	do	do	Center School district.	Slight elevation.	1	29	30	25	18	Seasonal		6		Hard	General	do	4.00
27	do	do	N. N. Hill Brass Co.	Stream bed	6	121	127	40	4		10+	6		Iron	General, factory.	Schist	3.25
28	do	do	A. N. Conklin		7	23	30	20	3			36		Hard	Domestic	Schist or granite.	3.35
29	do	do	F. S. Hall		22	14	36	28	22		5/6					do	
30			Mrs. I. H. Stone	Hill	0	142½	142½	142½	50		10	6		Med. soft.	Domestic	Gneiss	
31	Colchester		Dr. E. B. Craigin.	Hilltop	16	185	201	185	9		7	6		Iron		Schist	
32	do		Danl. W. Williams.	Slope			81					6		do	Stock	do	
33	do		Chas. N. Taintor	Hill	10	92	102	90	12	Siphoned and constant.		6		Iron, soft.	Domestic, stock.	do	3.50
												6					
34	Colebrook		H. D. Northrop	do	10	67	77	First at 55.	17		2½	6		Med	do	Gneiss	4.50
35	Coventry	Mansfield Depot.	Dr. F. E. Johnson	Plain	10	30	40	40			Small.	6	50	Soft	Stock	Schist	
36	Danbury		Geo. N. Frost	Slope	1½	44½	46	44	16		3	3	50	do		Granodiorite or gneiss.	
37	do		Chas. H. Brundage.	do	6	48	54	51	18	Constant	Good.	4	51	do	Domestic	Gneiss	
38	do		do		0	68	68	62	15		Very large.		48	do	Stock	do	
39	do		District school		3	69	72				Large.			do	General	do	
40	do		V. B. Buck	Hill	4	108	112		30		Good.	6		do	Domestic	do	
41	do		G. H. Knapp	Hill slope	6	65	71	71	6		Fair.	4	54	do	do	do	
42	do		Leonard Salmons	Plain	12	40	52		12		Small.	4	50	Hard	do	do	
43	do		Alexander Turner		30	152	182		20			6		Soft	Domestic, garden.		5.00
44	Darien		Geo. P. Brett	Hilltop	50	180	230	220	20	Constant	20	6		Hard	Domestic	Granodiorite.	
*45	do	Noroton Heights.	Fitch Home for Soldiers.	Small Valley	13	490	503	400	15		26	8	56		General	Gneiss	
*46	do	do	do	do	12	413	425	335–425	Flows+7	Pumping lowers to 80 feet.	4 flowing, 50 pumping.	8	53		do	do	
47	do		Dr. Delafield				126		18		10	6				Granodiorite.	
48	do	Noroton	William Zeigler	Island	Small.		200				Poor.			Salty		Gneissoid granite.	

[a] Additional details concerning wells marked * are given on pp. 90-91.

[b] Per day.

Records of wells in crystalline rocks of Connecticut—Continued.

No.	Town.	Locality.	Owner.	Topographic position.	Depth to rock.	Depth of rock.	Depth of well.	Depth of principal source.	Depth to water.	Variation of water level.	Yield per minute.	Diameter.	Temperature.	Quality.	Use.	Rock in which well is drilled.	Cost per foot.
					Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*		*Galls.*	*In.*	°*F.*				
49	Darien	Noroton	William Zeigler	Island	Small		1465				3			Brackish.		Gneissoid granite.	
50	Derby		Derby and Ansonia Brewing Co.	Valley plain	80	85	165				30	6				Granite	
51	East Haddam	Hadlyme	H. Weinstein	Slope	30	70	100	99	30		1	6		Hard	Domestic	Schist	
52	do	do	Allen Willey	do	3	57	60	55			Small.	6		Soft	Drinking	do	
53	do	Moodus	F. B. and S. P. Clark.	do	4	36	40				Good.			Hard	Domestic	do	
54	do		Geo. Wykes	Hill	0	100	100	75	53	Pumping lowers.	1½	6	40	Soft		do	
55	East Haven	Fair Haven	Andrew Holleran				66½				5	4		Med	General		
56	East Lyme	Niantic	Andrew Champion.	Coast, elevation 10 feet.	39	29	68	65	5	Constant	20	6			Domestic	Granite	
57	do	Crescent Beach	Atwood Collins	Plain	28	66	94	80	20		2½				do	Gneiss	
58	Easton		E. F. Wheeler	Hill	11	114	125	110	30	Slightly affected by pumping.	15	6	50	Soft	Sold	Granite, schist.	$4.75
59	Essex		Essex Wood Turning Co.	River flat			212							Salty			
60	Fairfield	Southport	J. H. Perry	Small elevation	10	158	168	160	10		3	5		Hard	Domestic	Schistose gneiss.	3.00
61	do	do	Miss Frances Wakeman.	Hill			190		10	Constant				Soft	do	do	
62	do	Greenfield hill	S. Pease		9	13	22	18	4			36		do	do		
63	Franklin	Yantic	G. E. Starkweather.	Slope			12	10				48		do	do	Schist or gneiss.	
64	Greenwich	Sound Beach	A. A. Marks	Slope, elevation 30 feet.	0	20	20	18	3	Seasonal				do	Boiler	Granodiorite.	
65	do		Emil L. Boas	do	65	235	300	240			12	8		Med	Domestic, garden.	Granite	
66	do		Mrs. A. W. Mansfield.	Hill	2½	117½	120	50	8		30	6		Iron	Domestic	Granodiorite.	
67	do		H. O. Havemeyer	do	35	140	175	150	50	Constant	50	6	55		General	do	7.00
68	do		Wm. S. Todd	Slope	10	133	143		10	Lowers		6		Soft	Domestic, stock.	Granite	
69	do		John Mahar	Slope	22	178	200	160	Flows.		Pumps 70					Granodiorite.	
70	do		Jaynes Parh	Base of hill	8	52	60	48	Flows.					Soft		do	

71	Greenwich	Sound Beach	E. C. Benedict		0	225	225				37			Brackish.		Granodiorite.	
72	do		do		0	265	265							do		do	
73	do		E. W. Bullinger		4	249	253				1						
74	Griswold	Glasgo	J. G. Bill	Hill	6	56	62	60	22		12	6	50	Hard	Domestic	Gneiss or gabbro.	
*75	do	Jewett City	Aspinook Co.	do			{30 / 60}		12–20		a 10			Soft	{Drinking, washing, bleaching.}	Gneiss	(b)
76	Groton	Eastern Point	J. Hunt Smith	Elevation 20 feet.	9	55	64	50	40	Said to vary with tide.		6			Domestic	Granite	
77	do		Thos. W. Avery	Hill	20	95	115	100	30	Rapidly lowered.	Poor.	6	50			do	
78	do	Eastern Point	do	do	15	45	60	40	10	Lowered to 35 feet.	Good.	6			Domestic	do	
79	do	Mystic	Miss Alice Damon.	do	12	74	86	86	6		2½	6		Med.	General	Granitic gneiss.	$4.00
*80	do	do	Oral school	do	20	528	548		10		21(?)				do	do	
81	do	do	Benj. Barrows	do	0	30	30		8		2						3.00
*82	do		J. F. & N. D. Sevin.	Slope, elevation 100 feet.	12	38	50	28–40	6		4	6		Med. hard.	Domestic	Granite	4.50
83	do		Capt. T. Hamilton.	Hill			290	280	30			6		Soft	do	do	5.75
84	do		C. H. Marquardt	do			100	90	30			6	45		General	do	6.00
85	do		G. W. Maxley	do	25	30	55		40	Pumps dry		6		Soft	Domestic	do	
86	do		Florence S. Kilern.	Coast plain			43		8			6		do	do	do	5.00
87	Guilford	Leete Island	Fred Butler	Hill	6	60	66	60	25	Pumping lowers.		6		do	Drinking	do	4.00
88	do	do	R. M. Leete	Slope	12	50	62	60	20	do	1	6	48	Med. hard.	General	do	3.75
89	do	Sachem's Head	N. E. Wordin	do	11	36½	47½	47	½	do	8	6	52	Hard	do	do	5.00
90	do	do	do	do	4	52	56	52	4	Pumping does not lower.	10+	6	52	do	do	do	5.00
91	do	do	F. A. Cummings	Hillside	1½	45½	47	45	35			6		Soft	Domestic	do	
92	do	do	Mrs. G. B. Mitchell.	Near shore	2	68	70		4			¼				do	
93	do	do	Eng. Fish	do	6	211	217		5		35			Salt		do	
94	do	do	do	do	0	43	43		8		1½					do	
95	Haddam	Higganum	E. L. Webb	Hill	3	57	60	30	28		Good.	6		Hard		Trap dike.	
96	Hebron	Turnerville	Edw. W. Bill	do	16	85	101	65	6		60	6		Hard, iron.	Domestic, stock.	Schist	4.00
*97	Huntington	Shelton	Sidney Blumenthal Co.	Valley	73	97½	170½									Granite and gneiss.	
98	do	do	Oscar Wright		25	76	96	96			8					50 feet phyllite slate, 21 feet granite.	

a Average.

b Total cost, $1,597 for nine wells.

Records of well in crystalline rocks of Connecticut—Continued.

No.	Town.	Locality.	Owner.	Topographic position.	Depth to rock.	Depth of rock.	Depth of well.	Depth of principal source.	Depth to water.	Variation of water level.	Yield per minute.	Diameter.	Temperature.	Quality.	Use.	Rock in which well is drilled.	Cost per foot.
					Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*		*Gals.*	*In.*	°*F.*				
99	Killingly	Danielson	S. C. Hutchins				50 80		0		4			Hard	General	Gneiss	
100	Madison		G. A. Wilcox	Rockyhill	8	55	63	63	8	Seasonal	Good.	6		Hard, iron.	Domestic, heating.	do	$5.00
101	do	North Madison	J. Heinemann	Hill	4	68	72				Large.	6		Soft	Domestic	Granite	
102	Mansfield	Storrs	Connecticut Agricultural College.	do	9	841	850	800	36	Pumping lowers slightly.	40	6	52	do	do	Schist	8.00
103	Middletown	Higganum	Inocente Tolette	do	18	132	150	125	8	Pumps dry.		6		do	do	Granite	4.00
104	Milford	Naugatuck Junction.	Chas. G. Root		30	45	75		30			6		Hard	do	Phyllite	
105	do	Naugatuck	J. O. R. Sheridan	Flat	0	43	43		6		1				General	Granodiorite.	
106	Monroe	Stepney Depot.	A. B. Curtiss	Slope	7	32	39		12	Constant		4		Soft	Domestic	Schist	
107	Montville	Uncasville	Mrs. E. R. Burchard.	do	20	80	100		15	do				Hard	do	Gneiss	
*108	do		Jacob Irons	do	2½	50	52½		2			6				do	
109	New Canaan		T. W. Hall	Hilltop	20	145	165	125	18	Constant	25	6	50	Hard	General	Granite	5.00
110	do		A. J. Gray	Slope	54	50	104		30	do	7	6	1	do	Manufacture of mineral waters.	do	5.75
111	do		B. Fischer estate	Ridge			130						50	do	Domestic	do	5.00
112	do		L. P. Child	Hill			156		64	Constant	15	6		do	General greenhouse.	do	
113	do		L. D. Alexander	Ridge	35	215	248	240	15	Pumping lowers.	Good.	5	50	Soft	Domestic	do	
114	do		C. F. Diefenteler		60	93	153	153	18	Pumping lowers to 50 feet.	20					do	
115	do	New Canaan	Sturgis Coffin	Hill	56	94	150		4		18	6				do	
116	do	do	Mrs. W. E. C. Bradley.	do	50	203	253		8		40	6				do.[a]	

117	....do.....	.....do.....	Dr. P. H. Williams.	.....do.....	48½	151¼	200	.....	5	Pumping lowers to 80 feet.	2	6	.....	.....	.....	...do.....	.....
118	.....do.....	.....do.....	Mr. Taggart.....	Slope.....	65¾	87¼	153	.....	20	.....	70	6	.....	.....	.....	Redgrowth	.....
119	.....do.....	.....do.....	Miss C. A. Bliss..	Hilltop.....	20	130	150	.....	4	.....	40	6	.....	.....	.....	Granite.....	.....
120	.....do.....	.....do.....	Theodore Terrill .	.....do.....	14	172	186	.....	9	.....	6	.....	.....	.....	.....	...do.....	.....
121	New London..	.....	Consolidated Street Ry. Co.	Elevation2 feet	60	73	133	.....	2	.....	.....	6	.....	Saline.	.....	...do.....	.....
122	New Milford..	.....	H. H. Hartwell..	Slope.....	5	60	65	60	5	.....	1½	4	48	Hard, iron.	Domestic..	.....	.....
123	.....do.....	.....	Mrs. O. W. Hoyt.	.....do.....	22	38	60	55	25	Seasonal...	2	4	51	Soft...	...do.....	Granite.....	.....
124	.....do.....	.....	Henry S.S. Kinnlin.	Hill.....	5	57	62	40	10	.....	.....	5	.....	Hard..	...do.....	...do.....	4.00
125	.....do.....	.....	W. D. Black....	.....do.....	.....	.....	250	.....	.....	.....	Good.	.....	.....	.....	...do.....	Limestone.	.....
126	.....do.....	Boardman.....	Benj. Houghtailing.	Valley.....	13	44	57	.....	30	.....	3	3	51	Hard..	...do.....	...do.....	.....
127	.....do.....	.....do.....	New England Lime Co.	Slope.....	5	45	50	.....	7	Constant..	Good.	.....	.....	.....	.....	...do.....	.....
128	Newtown.....	.....	C. G. Morris.....	Hill.....	.....	.....	20	.....	4-20	Dries in summer.	.....	36	.....	Hard..	.....	Granodiorite.	.....
129	Norfolk.....	.....	A. P. Curtiss....	.....	30	78	108	.....	11	Constant..	15	6	.....	Soft...	General...	Gneiss.....	3.00
130	.....do.....	.....	R. C. Burr.....	.....	49	17	66	.....	15	.....	15	.....	.....	.....	...do.....	...do.....	3.00
131	North Canaan	East Canaan..	A. A. Lawrence..	.....	18	19½	37½	30	15	.....	.....	40	44	Hard..	...do.....	Limestone	.....
*132	Norwalk.....	South Norwalk	Jos. Himmel.....	Island, elevation 8 feet.	.....	.....	125	20	8	.....	20	.....	.....	Salty..	Not used..	Granite....	5.00
*133	.....do	....do.....	Norwalk Iron Works Co.	Valley.....	80	....	260	60	6	.....	.....	8	.....	Hard..	Drinking..	...do.....	.....
134	.....do	....do.....	Meeker Union Foundry Co.	Valley, elevation 4 feet.	.....	.....	107	100	5	.....	Good.	6	45	.....	Drinking, boiler.	...do.....	4.00
135	.....do.....	.....	Joseph Burns....	Valley.....	.....	.....	247	.....	10	.....	25	6	.....	Salty..	Cooling....	...do.....	.....
136	Norwich.....	.....	Ulmer Tannery Co.	.....do.....	20	95	115	80	15	.....	10	6	.....	Soft...	None.....	Gneiss.....	.....
137	.....do.....	.....	Montville Street Ry. Co.	Foot of hill...	.....	.....	200	190	10	.....	.....	.....	52	.....	Boiler.....	.....	5.00
138	.....do.....	.....	Frich Co.....	.....do.....	0	265	265	170	100	.....	10	.....	.....	Hard..	None.....	Gneiss.....	6.00
139	.....do.....	Taftville.....	P. Dion.....	Hill.....	11	42½	50½	.....	30	.....	.....	6	.....	...do...	.....	...do.....	.....
140	.....do.....	.....do.....	Jos. Coron.....	.....do.....	0	75	75	.....	15	Seasonal ..	.....	6	.....	Soft...	Domestic..	...do.....	.....
141	.....do.....	.....do.....	AnthonyMurphy	Hillside.....	2	101	103	60	16	Constant ..	6	6	.....	.....	.....	...do.....	.....
142	.....do.....	Norwichtown .	Harriet M. Howland.	Hill.....	80	125	205	.....	10	Pumping lowers 6 feet.	8½	8	.....	Soft...	.....	Gneiss, gray blue slate.	.....
143	Orange.....	West Haven...	Ridgely Larkin..	Slope, elevation 30 feet.	20	54	74	74	10	.....	5	6	.....	...do...	Domestic..	Chlorite schist.	.....
*144	.....do.....	Woodmont....	John W. Merwin.	Hill.....	13	237	250	230	50	.....	Good.	6	.....	Hard..	Drinking..	...do.....	.....
145	.....do.....	.....do.....	J. I. Doolittle....	Plain.....	1	56	57	30-35	Few feet.	.....	Small.	6	.....	Very hard.	...do.....	Phyllite...	4.50
146	Plainfield.....	.....	J. C. Noyes.....	Slope.....	10	90	100	40	18	Pumping lowers.	.....	6	.....	Hard..	Domestic..	Gneiss.....	.....
147	.....do.....	Moosup.....	All Hallows Church Corp.	.....do.....	.....	.....	117	.....	.....	.....	.....	.....	.....	...do...	General....	...do.....	.....

a No water above 150 feet.

Records of wells in crystalline rocks of Connecticut—Continued.

No.	Town.	Locality.	Owner.	Topographic position.	Depth to rock.	Depth of rock.	Depth of well.	Depth of principal source.	Depth to water.	Variation of water level.	Yield per minute.	Diameter.	Temperature.	Quality.	Use.	Rock in which well is drilled.	Cost per foot.
					Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*		*Galls.*	*In.*	°*F.*				
148	Plainfield	Moosup	W. H. Wilson	Hill	15	18	33	30		General		8		Hard, iron.	General	Gneiss or schist.	$7.00
149	do	Central Village	G. P. Borjerson	do	3	52	55							Hard	do	Gneiss	
150	do	do	Torrey Bros	Valley	12	43	55	40	10	Constant	20	6	52	Hard, sulphur.	Drinking	do	
151	do	do	Plainfield Woolen Co.	Stream bed	30	132¾	162¾	160	20		20	6		Hard	General	do	2.75
152	do	Wauregan	John A. Baton				53½		Flow.		18			Med	Domestic, cattle.	do	
153	Plymouth	Terryville	Terryville Water Co.	Stream bed	30	70	100	100	Flows+3		30	8	50	Hard	Domestic	Schist	6.00
154	Pomfret		Mrs. M. V. Clark	Slope	18	592	610	600	25		12	6		Hard, sulphur.	Domestic, greenhouse.	Quartzite schist.	5.00
155	do		Wm. G. Jennings	Hill	98	7	105		43		5				General	do	
156	do		do	do	84	28	112		30		6				do	do	
*157	Putnam	Putnam Heights.	Mrs. R. P. Danielson.	do	55	365	420	55	20	Seasonal	2	6	51	Soft	do	do	
158	do	do	Dr. E. M. Harris	Slope	18	627	645		4		4	6		Hard	Domestic, stock.	do	
159	do		G. A. Pettis	Hill slope	18	94	112	110	30			6		do		Gneiss	3.00
160	Redding	Redding Ridge	Julia H. Sanford		7	78	85	65	20		Large.	6		Hard, iron.	Domestic	Schist	4.00
161	do	do	Lester Peck		52	96	148	138	15		30	6			General, stock.	do	3.00
162	Roxbury		Herman Behr & Co.	Hill			486				Dry.	6¼				Garnetiferous schist.	
163	Salisbury		Geo. E. Quaile	do	10	205	215	200	30	Varies	Large.	6	45	Iron	Domestic	Limestone	
164	Saybrook	Deep River	W. W. Jennings		30	48	78	68	2	Varies, occasionally flows.	Large.	6		Soft	do	Schist or gneiss.	4.50
165	Seymour		O. E. Hurlburt	Hill			88	88	20		4	6		do	do	Granite	
166	do		Mrs. J. W. Spencer.	do	22	52	74	70	12		2½	6	47	do	do	do	3.50
167	do		Catherine R. Warner.	do			280				Failure.	6				do	

168	....do....	....	Jas. Swan....	Slope....	....	....	280	60	12	....	40	....	....	....	General....	...do....	....
169	Sharon....	....	C. A. Low....	Hill....	25	146	171	....	20	....	....	6	....	Hard..	Domestic, garden.	....	....
*170	....do....	....	Miss E. O. Wheeler.	Slope....	100	15	115	110	70	....	15	....	....	Very hard.	Domestic..	Limestone.	....
171	Sherman....	....	Geo. A. Barnes...	....do....	12	58	70	50	20	....	Good.	4	....	Soft...	....	Gneiss....	....
172	Sprague....	Baltic....	N. R. Garden....	Hill....	3	38	41	15–25	3	....	....	120	....	....	....	...do....	....
173	....do....	....do....	St. Mary's R. C. Society.	Slope....	....	....	175	....	Flows.	....	9	6	....	Hard..	General....	Schist or gneiss.	4.00
174	....do....	....do....	Dr. S. Bouvier...	....do....	27	31	58	56	2	Constant..	12	....	....	Soft...	....	Gneiss....	....
175	....do....	Hanover....	Angus Park....	....do....	30	50	80	75	30	...do....	2	6	....	...do...	Domestic..	Schist or gneiss.	4.50
*176	Stafford....	West Stafford..	Ralph Brown....	....do....	21	26	47	47	22	....	....	4	50	...do...	...do....	Schist or granite.	5.00
177	Stamford....	....	H. S. Cammann..	Hill....	....	....	177	177	15	Pumping lowers to 30 feet.	50	6	....	...do...	...do....	Grano-diorite.	....
178	....do....	....	Patrick Boyle....	Plain, elevation 20 feet.	....	....	102	....	....	Pumping lowers.	Good.	6	....	...do...	...do....	...do....	....
179	....do....	....	Dr. A. J. Givens.	....	30	382	412	....	....	....	Very poor.	....	....	....	....	Paro-diorite	....
180	....do....	....	Clendenin Echert	....	25	161	186	....	52	....	70	....	....	Soft...	....	...do....	....
181	....do....	....	Diamond Ice Co..	Shore....	50	120	170	....	....	....	15	....	52	Med. hard.	....	Grano-diorite.	....
182	....do....	....	....do....	....do....	50	42	92	....	....	....	200	....	....	...do...	....	...do....	....
183	....do....	Sound Beach..	Mr. Dobbs....	Slope....	....	....	70	....	....	Pumping lowers to 50 feet.	20	....	....	....	....	...do....	....
184	Stonington....	....	Mrs. J. R. Chesebro.	Slope, elevation 30 feet.	3	98	101	78	29	....	1½	6	50	Hard..	Domestic..	Granite....	....
185	....do....	....	Atwood-Morrison Co.	....	28	143	171	30	15	....	11	6	....	Salty..	....	...do....	....
186	Thompson....	....	J. M. Chapin....	Hill....	7	45	52	40	7	Pumping lowers.	15	6	....	Hard..	General....	Gneiss....	3.00
187	....do....	....	J. N. Kingsbury.	....do....	15	60	75	....	12-18	....	15	6	....	...do...	Domestic..	...do....	....
189	....do....	....	Chas. E. Olney...	....do....	13	37	50	15–40	4	Seasonal...	2	6	....	...do...	Bathing...	...do....	....
190	....do....	....	N. B. Ream....	....	....	....	310	....	25	Pumping lowers slightly.	40	6	....	Iron...	Domestic..	...do....	....
191	....do....	....	John H. Wilkes..	Hill....	....	....	60	....	10	....	3	6	....	Hard..	Stables....	...do....	2.20
192	....do....	North Grosvenordale.	Grosvenor Dale Co.	Valley	15	275	290	....	4	Pumping lowers.	60	8 6	....	...do..	Drinking..	...do....	....
193	....do....	....do....	Mauritz Nelson..	Slope....	0	53	53	33	....	Dries....	2	6	....	...do..	General....	...do....	....
194	....do....	Willsonville...	Jos. Brault....	Hill....	7	39	46	....	10	....	6	6	....	....	...do....	...do....	4.00
195	Torrington....	....	S. A. Hermann ..	....do....	35	79	114	112	6	Constant..	10	6	50	Med. soft, iron.	Cooking, stock.	Granite....	3.00
196	....do....	....	Excelsior Needle Co.	Valley....	43	540	583	500–583	8	Pumping lowers to 250 feet.	25	6	....	Hard..	Drinking..	...do....	....

Records of wells in crystalline rocks of Connecticut—Continued.

No.	Town.	Locality.	Owner.	Topographic position.	Depth to rock.	Depth of rock.	Depth of well.	Depth of principal source.	Depth to water.	Variation of water level.	Yield per minute.	Diameter.	Temperature.	Quality.	Use.	Rock in which well is drilled.	Cost per foot.
					Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*		*Galls.*	*In.*	°*F.*				
197	Torrington		Thos. J. Stone	Valley plain	23	75	98	65	8	Lowers to 30 feet.	16	6	.....	Soft	Manufacturing mineral waters.	Granite	.....
198	....do		Torrington Mfg. Co.	Valley	50	54	104	90	9	.....	20	6	55	.....	Factory, drinking.	....do	.....
199	Trumbull		N. B. Curtis	Small elevation	18	32	50	48	8	Seasonal	.....	6	.....	Hard	Domestic	Schist or granodiorite.	$4.00
200	....do		E. S. Fairchild	Ridge	30	45	75	50	0	Pumping lowers to 40 feet.	Good.	6	.....	Soft	Domestic, boiler.	....do	.....
201	....do		Thos. L. Wade	Slope	16	69	85	75	25	Pumping lowers.	.....	6	.....	....do	Domestic	Schist or gneiss.	4.00
*202	Vernon	Rockville	B. L. Burr	Hill	6	54	60	58	46	....do	Good.	6	.....	....do	Drinking	Gneiss	.....
203	....do	....do	Horace G. Holt		25	7	32	.....	.....	.....	.....	6	.....	Hard	....do	....do	2.50
204	....do	Talcottville	Talcott Bros	Slope	97	230	327	.....	32	Pumping lowers.	7	.....	.....	.....	Domestic	....do	.....
205	Voluntown		John N. Lewis	....do	17	33½	50½	50	13	Constant	10	6	44	Soft	General	Granite	.....
206	....do		....do	Flat	.....	.....	50	49	13	....do	15	6	.....	....do	Domestic	....do	3.00
207	Washington		Dr. H. H. Hartwell.	Slope	5	60	65	.....	5	.....	2	.....	48	.....	.....	Schist	.....
208	Waterbury		Waterbury Brass Co.	Valley	80	80	160	160	13	Pumping lowers somewhat.	150	8 6	.....	Hard	Drinking, general.	Gneissoid schist.	4.00
209	....do		Platt Bros	....do	10	74	93	80	8	Pumping lowers.	.....	6	54	....do	Cooling	....do	.....
210	....do		Valentine Bohl Co.	Slope	60	120	180	.....	9	Constant with slow pumping.	35	6	52	Med	....do	....do	.....
211	....do		Waterbury Machine Co.	Valley	48	141	189	185	30	Constant	20	6	52	Hard	Drinking washing.	....do	.....
212	....do		Jean Jacques	....do	0	65	65	55	2	Pumping lowers.	4	6	50	Soft	Manufacturing ginger ale.	....do	.....
213	....do		Waterbury Mfg. Co.	Slope	20	330	350	300	3	.....	3½	8 6	.....	.....	Drinking	Granite	3.00

214	....do....	....	Franklin H. Kalbfleisch Co.	....	50	36	86	27	27	Pumping lowers 2 feet.	....	6	52-55	Hard..	Cooling....	...do....	....
215	....do....	....	W. P. Jarrett....	Hill.....	14	23	37	....	7	....	1	....	....	....	General...	Gneiss, schist.	....
216	....do....	....	....do....	....do....	10	32	42	....	7	....	1	....	....	....	...do....	...do....	....
217	....do....	....	....do....	....do....	14	48	62	....	4	....	1	....	....	....	...do....	...do....	....
218	....do....	....	....do....	....do....	20	11	31	....	11	....	4	....	....	....	...do....	...do....	....
219	Waterford....	Pleasure Beach	John O. Enders..	Plain, elevation, 80 feet.	18	100	118	80	16	Pumping lowers.	$6\frac{1}{2}$	6	....	Soft....	...do.....	Granite.....	....
220	....do....	....do....	Booth Bros.....	Plain.....	17	63	80	....	....	...do.....	....	5	....	....	Boilers....	...do.....	....
221	....do....	....	Fred C. Crowell..	Slope.....	7	36	43	13	11	....	Good.	6	....	Hard..	General....	...do.....	....
222	....do....	....	Maj. H. A. Hull..	Hill.....	58	15	73	40	12	Constant..	....	6	....	Soft....	...do.....	Gneiss.....	....
*223	....do....	....	Angeline W. Hill.	....do....	6	45	51	35	26	....	Large.	6	....	...do....	....	...do.....	....
224	Westbrook....	....	Mrs. J. H. Ripley.	....do	0	87	87	....	....	Pumps dry	Small.	6	....	Iron...	Domestic...	...do.....	....
225	....do....	....	A. C. Knothe....	....do....	10	90	100	....	60	....	5	5	....	Soft....	...do.....	...do.....	....
226	....do....	....	R. H. Stannard..	....do....	3	47	50	45 50	4	....	....	6	....	....	....	...do.....	....
*227	Westport.....	....	Atlantic Starch Works.	Valley	34	181	215	48 200	....	Pumping lowers to 15 feet.	60	8 6	50	Hard..	Factory (not boilers).	...do.....	....
228	....do....	Greens Farm..	Dr. Graham Hammond.	....	30	118	148	20	....	....	5	....	....	....	....	Schist.....	....
229	....do....	Saugatuck.....	A. W. Smith.....	Hilltop.....	15	79	94	35	30	....	15	6	54	.....	None.....	...do.....	....
230	Wilton.....	....	J. C. Berringer....	....	16	10	26	....	10	Seasonal...	....	36	....	Soft...	Domestic..	Granodiorite.	....
231	Winchester....	Winsted.....	L. J. Comstock...	....	....	....	102	....	Flows...	....	$2\frac{1}{2}$	6	....	Med...	Domestic, stock.	.....	....
232	Windham.....	....	Holland Mfg. Co..	Valley.....	5	95	100	....	4	Pumps dry	....	6	....	....	....	Gneiss.....	....
*233	Woodbridge...	....	Geo. D. Watrous.	Hill.....	....	....	75	....	15	....	Small.	6	....	.....	Domestic..	Phyllite.....	....
234	....do....	....	Edwin Judge....	Valley.....	0	15	15	12	7	Seasonal...	....	24	....	Hard...	...do.....	Slate, schist	....
235	....do....	....	Wm. Peck.....	Hill.....	15	15	30	....	10	...do.....	....	48	....	Soft....	...do.....	Slaty schist	....
236	....do....	....	W. J. Lum.....	Slope.....	20	44	64	54	12	....	$1\frac{1}{2}$	6	....	...do...	Domestic, stock.	Chlorite schist.	2.35
237	....do....	....	J. T. Newton.....	....do.....	9	141	150	....	Flows $1\frac{1}{2}$	Slight seasonal.	....	6	52	.....	Sale.....	...do.....	....

Additional records of wells in crystalline rock of Connecticut.

[Furnished by C. L. Grant.]

No.	Town.	Locality.	Owner.	Depth of well.	Depth to water.	Yield per minute.	Probable rock in which well is drilled.
				Feet.	*Feet.*	*Gallons.*	
1	Andover		R. P. Chapman	60	38		Schist.
2	Bolton		Mrs. M. C. Baker	105	11	28	Granite.
3	Branford	Stony Creek	Wm. F. Clark	60	28		Do.
4	do	do	Maltby, Stevens & Maltby	30	7		Do.
5	Bridgeport		Hutchinson, Pierce & Co	325	24	25	
6	do		Naugatuck Valley Ice Co	200	18	24	
7	do		F. Armstrong	135	3		
8	Bristol		Bristol Brass & Clock Co	100		30	Do.
10	Brooklyn		Brooklyn Cemetery	70	45		Gneiss.
11	do		S. H. Bowen	40	0	11	Do.
13	Canton	Collinsville	H. P. Chandler	20	1	18	Granite.
14	do	do	H. P. Reichert	30	10	3	Do.
15	Coventry	South Coventry	C. E. Rood	44	20		Gneiss.
16	do	do	Thos. Joyce	95	40	6	Do.
17	do	do	Martin Hughes	36	2		Do.
18	Griswold	Jewett City	A. Brown	40	30		Do.
19	do	do	Chas. Meech	57	0		Do.
20	Groton		Mrs. J. E. Keeney	51	15	6	Granite.
21	Mansfield		Edwin Reynolds	40	4	6	Schist.
22	Milford		W. M. Merwin & Sons	93	3	35	Do.
23	do		Chas. Coupland	90	9	7	Do.
24	do		D. E. Smith	58	21		Do.
25	do		Mrs. E. P. Smith	35		12	Do.
26	do		J. W. Kelly	100	24	18	Do.
27	Naugatuck		C. H. Hoffman	25	12		Granodiorite.
28	do		Olaf Swanson	31	18	3	Do.
29	New Canaan		Mrs. A. M. Bradley	253	11	40	Granite.
30	New London		N. L. Brewing Co	60	Flows.	110	Do.
31	Norwich		Thames Iron Works	61	5	30	Gneiss.
32	do		do	124	4	110	Do.
33	do		N. D. Sewin	50	3	4	Do.
34	do	Norwichtown	M. Cryer	30	12	7	Do.
35	Old Lyme	Lyme	R. S. Griswold	23	8		Granite.
36	do	do	do	42	20		Do.
37	Plainfield	Wauregan	Wauregan Mills Co	45	10		Gneiss.
38	do	do	do	158		40	Do.
39	do	do	Henry Woods	33	21		Gneiss or gravel.
40	do	do	Charles Carter	29		18	Do.
41	do	do	Nelson Willett	63	14	16	Do.
42	do	do	J. W. Atwood	55	20	18	Do.
43	do	Moosup	W. H. Wilson	36	0	5	Schist or gneiss.

44	....do	....do	Joseph Potwin	175	56	8	Do.
45	....do	....do	....do	89	24	12	Do.
46	....do	....do	....do	125	35	10	Do.
47	....do	....do	Benj. Lamont	60	12	.....	Schist, gneiss, or gravel.
48	....do	....do	E. E. Salisbury	33	7	3	Do.
49	....do	....do	Rev. J. A. Creeden	29	1	18	Do.
50	....do	....do	J. A. Paine	40	14	3	Do.
51	....do	....do	Henry Daggett	60	5	5	Do.
52	Pomfret		Mrs. Gertrude Vinton	70	666	1	Do.
53	Seymour		Tingue Mfg. Co	129	34	60	Granite.
54	....do		....do	80	11	60	Do.
55	....do		Joseph Reigel	110	29	11	Granite or schist.
56	....do		Patrick Ryan	17	1	33	Do.
57	....do		Jas. Swan	57	10	6	Do.
58	Stamford		Dennis Beach	130	11	25	Do.
59	Sterling		G. Anderson	45	15	9	Do.
60	Thompson		Henry Elliott	46	.....	2	Do.
61	Vernon	Rockville	N. E. Engineering Co	80	.....	25	Gneiss.
62	Waterbury		Wm. H. Smith	160	14	35	Gneiss or schist.
63	....do		Mr. Fitzsimmons	60	28	5	Do.
64	....do		Waterbury Clock Co	500	29	7	Do.

NOTES.

2. Penetrated 20 feet of loam and hardpan, 10 feet of soft rock, 20 feet of hard rock, and 46 feet of soft pulpy micaceous rock. Water was obtained in the soft micaceous rock. (See fig. 14.)

7. Dug and blasted 28 feet and drilled 22½ feet. Passed through 2 feet of loam, 12 feet of till with a 1-foot layer of iron-cemented material, 14 feet of disintegrated rock, and 22½ feet of hard rock.

10. Water salty on first being pumped but becomes fresh with continued pumping.

18. In drilling, considerable amounts of water were encountered in the sand and gravel above the rock. This water was cased out and a small amount was found at a depth of 25 feet in the granite, and additional supplies, increasing in small amounts, were found down to a depth of 150 feet. Below this point no new supplies were encountered, although the total depth of the well is 315 feet. The material penetrated was as follows: Sand and gravel, 50 feet; granite, 100 feet; clay and gravel (probably disintegrated rock marking a shear zone), 20 feet; soft white micaceous rock followed by granite varying in hardness every few feet (probably gneiss).

45 and **46.** Maj. William Spittle has furnished the following information: One well was drilled to a depth of 425 feet through 12 feet of clay till and 413 feet of granitic rock, of nearly the same character for the entire depth, probably a gneissoid granite. Water first began to flow over the surface at 335 feet from the top and continued to increase slowly in the amount of flow and in the height of the rise above the surface with increasing depth. At present the water will rise at least 7 feet above the surface of the well in a ¾-inch pipe. In five months' continuous flowing the volume of water decreased from 4 to 3 gallons a minute. When pumped the well yielded 50 gallons a minute and the water level was lowered to 80 feet below the surface and remained steady. The second well was sunk 130 feet away and at an elevation 4 feet higher to a depth of 503 feet. This well yields 25 gallons a minute, but the water stands at a level 15 feet below the surface. The pumping of the second well did not affect the yield of the first.

75. Mr. H. B. King has furnished information regarding five wells drilled for the Aspinook Company at Jewett City. They are from 15 to 100 feet apart and from 30 to 60 feet in depth, all penetrating 6 to 8 feet of sand and gravel. They are located on a hillside at varying elevations. These wells each average 20 gallons a minute and are all connected to a siphon which conducts the water to the mill at an elevation about 75 feet lower than the wells. Two of these wells, 15 feet apart, affect each other's yield, but the remaining wells are apparently independent of one another.

80. A small stream of water was encountered at 83 feet from the surface, and at 180 feet a stream of 1 gallon a minute; below this there was no increase in supply to a depth of 530 feet.

82. At a depth of 32 feet this well yielded 1 gallon a minute and at 38 feet 4 gallons a minute. The last 10 feet of the well gave no increase of supply.

97. Filling, 5.5 feet; silt, 5 feet; coarse gravel, 13.5 feet; coarse sand, 36 feet; hardpan, 13 feet; gneiss, 62 feet; granite or hard gneiss, 25 feet; slate, 5 feet; granite or hard gneiss, 5.5 feet. The total depth of the well is 170.5 feet. (See fig. 14.)

108. On the slope of a hill near the base of which are numerous springs. The water is siphoned from the well to tenement houses below. In dry seasons the level of water in the well drops 2 feet.

132. Drilled on a small island in Long Island Sound. A trace of fresh water was obtained at 125 feet, but the remaining supply was salty.

133. Fresh water was obtained at a depth of 60 feet, evidently from gravel deposits, but salt water was encountered in the rock seams below this point. The well was plugged below 60 feet and the fresh water from the gravel is utilized.

144. No water was found in the first 100 feet. In the next 70 feet a small amount was obtained, possibly 40 gallons a day, and the water stood at a level 107 feet below the surface. The well was drilled to a depth of 250 feet and an excellent supply obtained at 230 feet below the surface. Information furnished by H. B. King, the driller.

157. The water comes from the contact of the overlying clay and the solid rock. No water was found in the rock, which is a quartzite schist, although 365 feet of rock were penetrated.

170. The following log is furnished by the driller, A. J. Corcoran: Solid clay, 15 feet; clay and small stones (till), 10 feet; dark gravelly material, 46 feet; loose blocks of rock, 29 feet; soft and dry decomposed rock, 10 feet; hard rock, 5 feet. A small yield of water, 2 gallons a minute, was found at a depth of 30 feet, but no more was encountered until the last 5 feet of hard rock was penetrated, when a supply of 15 gallons a minute was obtained. (See fig. 14.)

176. Water was found in the superficial drift, but was lost on encountering a dry seam in the rock.

202. A good supply of water was obtained at a depth of 25 feet, but this flowed off at 45 feet, and when water was struck again at 60 feet it rose to this point and flowed off in the open rock seam.

223. At 35 feet the well pumped 100 gallons an hour and the water rose within 16 feet of the surface. A second and very large supply was encountered at a depth of 51 feet and the level of the water dropped to 25 feet below the surface.

227. Penetrated 34 feet of gravel and bowlders and 41 feet of micaceous rock, in which a little fresh water was found at 38 feet below the surface and a large flow of slightly salt water at 48 feet below the surface. The rest of the well was through a rock described as gray and yellow sandstone (probably schist). At 200 feet very salt water was encountered, but this is held back by a plug. (See fig. 14.)

PRACTICAL APPLICATIONS.

PERCENTAGE OF FAILURE OF WELLS.

Wells in crystalline rocks are unlike most other wells, in that it is impossible to predict their success or failure, even when numerous wells have been sunk previously in the same locality. For this reason a well driller will rarely guarantee to obtain water from such a well, although occasionally water is guaranteed and an additional price per foot charged to offset the driller's risk of failure.

When a well is considered a failure the fault lies either with the quality or with the quantity of the water obtained. It is a very exceptional well in which no water supply is obtained in the rock. Nearly all wells encounter some water in the surface material above the rock, but it is common for the drill to penetrate 30 or 40 feet of rock, and occasionally even 100 feet, without obtaining enough water in the rock to keep the drillings wet, so that water must be poured in at the top to allow the drilling to continue. Although no satisfactory data are at hand regarding the number of wells which have failed to obtain any water, it is certain that the number is very small. Among 237 wells only 3, or 1.25 per cent, are recorded as obtaining no water. Drillers are naturally averse to giving infor-

mation regarding unsuccessful wells which they have sunk, but the available information indicates that, though dry wells are uncommon, there are a considerable number of wells in which the yield of water has been less than 2 gallons a minute. For certain purposes, such as manufacturing, this small supply would be considered a failure, but for domestic use where the water is obtained by a hand pump or windmill a supply of this amount is generally sufficient. Among 134 wells whose yield is known, only 17, about 12.5 per cent, furnish less than 2 gallons a minute. It is probably a conservative estimate to state that not less than 90 per cent of the wells sunk in the crystalline rocks have given supplies of sufficient amount for the use required.

The greater number of unsuccessful wells in regard to quality are located along the coast or on tidal rivers, where the well supplies are affected by sea water. When a well is within a few hundred feet of salt sea water, it sometimes happens that salty or brackish water is obtained, although perfectly fresh water is yielded by other wells in similar locations. Six wells are recorded in which the water has been contaminated in this way and others, regarding which definite information is lacking, are known to have been failures for the same reason. It is certain that a large percentage of wells near salt water have yielded brackish water and any well sunk in rock on a small island or within 500 feet of the sea is likely to afford an unsatisfactory supply. As nearly as can be estimated from present information, the chances of failure for such wells are between one in four and one in three.

When there is a choice of several locations, the well should be as far as possible from the sea and at as high elevation as convenient. Several wells that have been ruined by the entrance of salt water are situated on old salt marshes or on filled ground that is but slightly elevated above tide level. In the quarry at Millstone Point, near New London, which is about 150 feet from the sea, brackish water enters through the horizontal seams in the upper part of the quarry wall nearest the Sound. The rock outcrops in the sea and the open seams have abundant opportunity to absorb salt water.

VARIATIONS IN YIELD AND DEPTH.

The depths and yields of wells vary widely within very small areas. When considered collectively, as in the table on page 102, it is seen that there is an average increase in the amount of water obtained with increase in depth of the wells. It is often found, however, that of two wells sunk within 100 feet of each other in the same kind of rock, one will obtain a plentiful supply of water while the other may be sunk to twice the depth and obtain only one-tenth the amount. This is a typical case which nearly every Connecticut well

driller will present in one form or another when information regarding his drilling experiences is requested.

This variation within short distances is due to the varied occurrence of the water-bearing fractures considered on the previous pages. One well may be sunk in a portion of the rock in which the fractures are numerous and closely spaced or it may intersect a large open fracture; the second well, only 100 feet away, may be located in an area of widely spread fractures or it may intersect only fractures with closely compressed walls and consequently can obtain only a meager water supply. Owing to the general steep pitch of joint planes, there would be little chance of two wells intersecting the same fracture, although they might possibly intersect connecting fractures and in this way affect each other's yield. Even where two wells intersect connecting fractures at the same depth, the yield of the two wells would probably be different, owing to differences in the opening of the fractures.

LIMIT OF DEPTH FOR WELLS IN CRYSTALLINE ROCKS.

Although the well records given on pages 78–89 show that supplies of water have been obtained at all depths from 15 feet to 800 feet, the largest percentage of failures is among the wells more than 400 feet in depth. The reasons for the increasing probability of failure with increasing depth are indicated in the discussion of joints (pp. 61–64), where it is shown that increased depth means a decrease in number and a tightening of joints. Increased depth usually means an increase in the cost per foot, as drilling is necessarily slower and consequently more expensive at considerable depths. Owing to the great length of rope and the necessity of waiting for the recoil of the stretched rope fewer blows can be struck per minute and there is also greater danger of losing the drilling tools.

In view of the increasing cost and the decreasing probability of finding water-bearing seams with increasing depth, and of the great variation in water-bearing fractures within very short distances, it seems manifest that if a well is unsuccessful within a certain depth the best policy is to abandon the well and start a new one at some distance from the first. In one place a well was abandoned in this manner and a second and successful one sunk by simply turning the rig around and drilling a hole less than 20 feet away. It is always preferable, however, to move as far away from the first well as possible.

In deciding at what depth an unsuccessful well should be abandoned a number of factors must be taken into consideration, but an estimate that will prove of value may be made from the available well records. The table on page 100 shows that the average depth

of the wells varies considerably for different rocks. The average depth in rock of 163 wells is 88.8 feet and the average total depth, including the surface material overlying the rock, is 108.4 feet. About 90 per cent of the wells are under 300 feet in depth and 82 per cent under 200 feet. In many of the wells which have gone below 250 feet the main supply and in several the entire supply has come from seams less than 250 feet in depth. From a study of the recorded wells it would appear, therefore, that if a well has penetrated 250 feet of rock without success the best policy is to abandon it and sink in another location. For wells in granodiorite, which have been successful at an average greater depth than in other rocks, this depth might be somewhat too small, but for wells in other rocks it is possible that a maximum depth of 200 feet should be adopted.

The wells that penetrate 200 feet or less of rock show a rather regular increase in yield of water with increasing depth, but in deeper wells than this the tendency is toward a smaller average yield owing to the failure of many of the wells. The average yield of 123 wells in the crystalline rocks is 12.7 gallons a minute, and as their average depth is 108 feet the cost of the average well for this yield of water at $4.25 a foot is $459.

QUALITY OF WATER.

A general discussion of the chemical composition of well waters and a number of analyses of well waters derived from crystalline rocks may be found on pages 166–168, 176–179. The general quality of water from these rocks is excellent and they are well adapted to boiler use.

TEMPERATURE OF WATER.

The temperature of the water is entirely dependent on the depth from which it comes. In wells less than 50 feet deep the water will show variations in temperature agreeing in a modified form with the seasonal changes. In wells more than 50 feet in depth the temperature of the water increases at the rate of about 1° to every 60 feet of depth. The average temperature of the water of 49 wells in the crystalline rocks is 50.5° F. The average annual temperature of Connecticut is 47° F.

LOCATION OF WELLS.

So many factors are involved in considering the location of a well that it is impossible to lay down any set rule for choosing a location. Before sinking a well it is always advisable to find out what wells have been sunk in the vicinity and what success they have had. The list of well records on pages 78–89 gives all the information at hand, although there are probably as many more wells in Connecticut regarding which no information has been obtained.

In localities where, owing to limited space or other factors, there is only one place where a well can be sunk, the only questions to be considered are the possibility of obtaining a satisfactory supply and the probable cost. For such wells the information embodied in this report should be of considerable value.

Where there is a choice of situations for the well the following points should be considered. The well should be as far removed from contaminating influences as possible. This is particularly important for wells near sea water. (See p. 174.) It is better to sink the well where there is a heavy covering of surface material rather than on a bare rock ledge. If there are rock exposures near by, a study of the joints may be of assistance in locating the well so as to intersect possible water-bearing fractures.

The Aspinook Company, at Jewett City, has adopted a very successful scheme which doubtless could be used in many other places. The mill is located below a hill and a series of wells were sunk on the hillside at a considerable elevation above the mill. The water is obtained by means of a siphon and a very considerable pumping expense is thus saved. The same method has been adopted for individual wells elsewhere and has proved satisfactory.

In order that a siphon may be used, the water level must be not more than 30 feet from the surface and the lower end of the siphon pipe or the escape valve must be at an elevation lower than the water level. The average depth from the surface of the ground to the water level in the recorded wells is 19 feet on hills and 15 feet on slopes. The water level will of course lower to some extent when water is drawn out and the degree of lowering will be proportional to the volume of water removed, but in many wells the lowering will not be sufficient to affect the use of the siphon. The greatest certainty of success will be on hillsides where there is a covering of clay or hardpan and where there are no outcrops of rock showing above the surface at elevations lower than the top of the well.

The wells located on hills average less in cost than those in valleys, owing to the greater depth of the valley wells, as shown in the table on page 102; but the average yield of wells on hills and in valleys is nearly the same.

CONSTANCY OF YIELD.

The wells appear to maintain a remarkably constant yield from year to year. Although the drilling of wells in the crystalline rocks is a comparatively new venture and almost all of these wells have been sunk in the last three years, no well in which water was obtained has failed to yield a supply on continued use. In very shallow wells dry seasons have marked some decrease in supply, but the decrease has been small and only temporary. In a number of wells the sup-

ply has increased after continued pumping, probably owing to the removal of material lodged in the rock crevices, which are cleaned out by the running water.

In some wells supplies obtained at short distances below the surface have been lost with deeper sinking, an open dry crevice struck at a lower level allowing the water to run off. Such occurrences are unusual and are found at relatively shallow depths. During the drilling of any well it is usual to find a number of fractures supplying water. Often the water derived from small sources will stand at a certain level in the well and when the main supply is struck will rise or fall, depending on the height at which the water stands in the main crevice. There will of course be an equalizing between the various supplying fractures. If the well penetrates one saturated fracture in which the water stands at 10 feet below the top of the well and a second fracture in which the water stands at 30 feet below the top, the water level in the well will occupy an intermediate point somewhere between 10 and 30 feet below the surface.

FLOWING WELLS.

The question is often asked regarding the possibility of obtaining flowing wells in Connecticut. A number of flowing wells have been obtained in the sandstone area in the central and northern portions of the State, but a flowing well in crystalline rocks is a very unusual occurrence. Information has been obtained regarding six wells in the Connecticut crystalline areas in which the water has maintained a constant flow over the top for some time and several wells are known in which the water has flowed over the surface for a few minutes but has eventually lowered to a level below the mouth of the well.

The occurrence of flowing wells is therefore common enough to demand an explanation. Four of these wells have been personally visited and the position of the others is known approximately. Each of the wells is located on the side slope of a hill or in a small valley where there is a considerable elevation back of the well. One well at Greenwich is on a very gently sloping surface so that it appears to be at the top of the hill, but in reality the ground rises gradually to an elevation at least 40 feet higher than the well. All the wells are in markedly glaciated areas, where there is a considerable thickness of clay till overlying the rock, and there are no neighboring rock outcrops except at one flowing well called the Buttress Dyke Spring, near New Haven. This well is in an area of schistose rock where the hill back of the well exhibits numerous outcrops, but there are no rock ledges showing at elevations lower than the well.

From the study of the individual wells and of the general occurrence of water in rock fractures, it is concluded that the artesian conditions

A. FLOWING WELL AT NOROTON HEIGHTS.

B. WEATHERING DUE TO GROUND WATER IN GRANITE QUARRY.

giving rise to flowing wells in Connecticut are due solely to the capping of clay till above the rock and that this capping is sufficiently impervious to prevent the water escaping from the rock crevices, at least with sufficient freedom to destroy the artesian head. The water occupying the rock seams is under hydrostatic pressure owing to its confinement on the sloping hillside, and, an easy escape being offered by the open well, the water rises to the surface. It is probable that the joints that give rise to the flowing wells are more nearly at right angles to the slope of the hillside than parallel to it. The same conditions might arise where the joints have a pitch parallel to the surface slope and a very low inclination, but the pitch of most of the joints is so steep that they would intersect the surface so near the well as to give little or no head to the water.

As far as water supply is concerned, flowing wells need not be considered as of any particular importance in Connecticut. In the first place it is impossible to predict that a well will flow, even though the most favorable location be chosen. At Noroton Heights two wells were sunk within 150 feet of each other in the same kind of location, one of which flowed 7 feet above the surface, while in the other the water rose only within 15 feet of the top. Second, the flow at each of the flowing wells has been small, from 1 to 4 gallons a minute. This supply is too small for the use made of it at most of the wells and pumping machinery has been installed. The wells have yielded unusually large supplies when pumped, but the level of the water has sunk to a considerable distance below the surface. It is not known whether the wells would again flow if pumping were stopped. (See Pl. III, *A*.)

It is probable that in the wells which flowed for only a few minutes after being struck the water then found an escape through open dry fractures in the upper portion of the well, as the water level dropped to several feet below the surface.

WELLS IN VARYING ROCK TYPES.

A study of joints and other rock fractures indicates that these structures vary with varying rock types, and as the water supply of wells is directly dependent on the fractures it is to be expected that there will be corresponding variations of supply in the wells in the different rock varieties. These variations are discussed below. The records on which the discussion is based are not as complete as might be desired, but are sufficiently numerous to have considerable weight.

Wells in granite.—It has been shown that the fractures particularly characteristic of granite masses are the nearly horizontal joints which in general run parallel to the surface of the ground. These joints are manifestly of considerable importance in the transmission and storage of water, but it is doubtful whether they are sources of

large supply to wells. In granite quarries where the horizontal joints are well developed, the greater portion of the water entering the quarry comes through these flat joints. Owing to their parallelism to the surface these joints are not in a suitable position to receive water from the material overlying the rock, and must get their main supply of water from that descending through the vertical joints. In the quarry walls the largest amount of water escapes and the heaviest decomposition of the rock occurs near the major vertical joints, indicating that the vicinity of such joints is the place of greatest water circulation.

As a well sunk in granite must pass through a large number of horizontal seams, which are far more abundant in the upper 50 feet of rock than in the next 50 feet, it would appear that if these seams were saturated and could yield good water supplies the granite wells should furnish unusually large supplies at comparatively shallow depths.

The records show, however, that the wells in granite yield about the same as those in gneiss and schist, and that although their average depth is 10 per cent less than that of the wells in gneiss it is slightly greater than the average of the schist wells. The natural inference to be drawn is that though the number of contributing fractures to any one well is much greater in granite than in the other two main rock types, the total yield of the well is no greater than the amount furnished by the vertical joints to the horizontal joints.

In granite the vertical joints are more irregular and probably more widely spaced than in the other rock types, but they are well connected with one another by the intersecting horizontal joints. The contributing area to a granite well should occupy a space with an approximately uniform radius around the well.

Wells in schist and gneiss.—Little difference can be distinguished between the occurrence of joints in schist and that in gneiss, and in fact the two rocks grade into each other so completely that it is in some places difficult to say whether a rock is a schist or a gneiss.

The marked development of horizontal joints characteristic of granite is lacking in these rocks, and the more regular character of the vertical joints tends to produce a different manner of circulation through the rock. A single well, instead of drawing water from an area surrounding it on all sides, will draw from long distances through the feeding fractures and the vertical fractures connecting with them.

The wells in schist and gneiss have nearly the same average yield, but those in gneiss average 15 per cent deeper than those in schist. It is possible that the supply for the wells in schist comes not only through the joints but also through fissility openings or small fractures parallel to the schistosity. Such fractures are common near

the surface, and owing to their inclination might well absorb considerable volumes of water. Because of the small size and lack of continuity of these openings they would yield water very slowly to the well, but might give an important amount in the aggregate. The derivation of a supply through such openings, which would have their greatest development near the surface, would account for the relative shallowness of wells in schist.

That fractures parallel to the schistosity may be important carriers of water is well shown on the east bank of Connecticut River above Hadlyme Landing, where there is a long exposure of fissile schist and a number of small springs issue from partings parallel to the schistosity.

Wells in quartzite schist.—In the northeastern portion of the State there is an important development of a rock which is a schist but is unlike most of the schists of Connecticut and will be treated separately. This rock is an altered quartzite and consists very largely of quartz grains with a very small percentage of other minerals. No study was made of the fractures in this rock, but information has been obtained regarding five wells which were drilled in it, three of which are more than 300 feet in depth and one more than 200 feet. In each one the supply has been very small and unsatisfactory. Though the number of these wells is small, the evidence indicates that the rock is a very unreliable source of water supply and that the fractures are few or poorly developed.

Wells in phyllite.—Near Woodbridge and at Woodmont several wells have been drilled in a greenish slaty rock or phyllite in which the supplies have proved very unsatisfactory. The cleavage of the rock is nearly vertical, causing difficulty in drilling, and most of the fractures appear to be filled by some cementing mineral matter. The wells that have been drilled in this rock are comparatively shallow, but the water obtained has been so universally poor that the probability of getting a satisfactory supply appears to be very slight.

Wells in limestone.—Comparatively few wells have been drilled in the limestone area in the western part of the State, where springs are so numerous as to constitute far the most important source of water supply. The limestone itself is largely recrystallized and changed to a marble. It is dolomitic in part, but unlike many dolomites is compact and contains very little pore space.

The fracturing is very thorough and in fact so complete that it has been found impossible to obtain blocks for building purposes large enough to warrant quarrying. The limestone is traversed throughout by irregular fractures which divide it into a series of comparatively small blocks. Solution is very effective in limestone, as the calcium carbonate constituting the bulk of the rock is readily soluble in water containing carbon dioxide. No large solution caverns, such as

are typical of many limestones, have been found in the Connecticut limestones, but the fractures generally have decomposed borders several inches wide and are sufficiently enlarged to offer easy passage to water.

Wells should be very successful in this rock, but because of its highly fractured condition water passes through it rapidly and the level of the water in the wells will probably be at a greater distance below the surface than in rocks of other types.

Wells in granodiorite.—In the vicinity of Stamford and Greenwich the wells drilled in schistose granodiorite have met with a considerable degree of success. The rock outcrops in this area show a well-developed and rather closely spaced jointing which is nearly at right angles to the schistose structure of the rock. There is no apparent reason why the wells in this rock should differ from those in schist and gneiss, but the average depth and average yield are much greater. It is possible that especially large supplies have been required in this locality and that for this reason the smaller supplies in the upper portion of the rock have been insufficient and the wells have been drilled until a large supply was struck.

STATISTICAL TABLES.

TABLE 1.—*Yields of water at varying depths in the rock below the covering of surface material.*

["Vol."=average yield in gallons per minute; "No."=number of records from which the average is taken.]

Depth in feet	0–30		30–50		50–70		70–90		90–110	
	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.
Schist	3.2	2	.....	.....	9.5	4	21.6	3	22.1	6
Granite	7	1	6.7	9	9.8	5	20.5	2	14.4	8
Gneiss	1	1	11.9	13	12.4	14	7.6	7	5.5	2
Granodiorite	.....	.....	.....	.....	.....	.....	8.0	.....	0	1
Quartzite schist	.....	.....	.....	.....	.....	.....	6.0	1	.....	.....
Average	3.6	4	9.75	22	11.3	23	12.4	14	15.2	17

Depth in feet	110–200		200–300		300–400		400–500		500–650	
	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.
Schist	8.5	2	.....	.....	.....	.....	0	1	.....	.....
Granite	13	5	16	3	0	1	50	1	.....	.....
Gneiss	8.3	8	33.0	2	22.0	2	.....	.....	14.0	2
Granodiorite	46.0	6	10.7	3	2	1	.....	.....	.....	.....
Quartzite schist	.....	.....	0	1	2	1	.....	.....	7	2
Average	20.2	21	16.7	9	11.5	4	26.0	5	5.2	4

NOTE.—The information at hand shows no relation between the depth of the surface drift and the yield or success of wells.

TABLE 2.— *Yield of wells more than 400 feet deep, with reference to topographic position.*

Location.	Depth in feet.	Yield (gallons per minute).
Valleys	583	25
	690	[a] 10
	503	26
	425	50
Hills	850	40
	548	Poor.
	420	2
	486	Dry.
Slopes	610	12
	645	4
Island	1,465	[b] 3

[a] All water obtained at 120 feet. [b] Salty.

TABLE 3.—*Average yield of wells in various locations.*

Location.	Average yield (gallons per minute.	Number of records.
Valleys	24.4	18
Hills	20.6	27
Slopes	8.7	25
Plains	18.8	9

TABLE 4.—*Relation of average yield of wells in various topographic locations to average yield of wells in any rock type and in any location.*

[Yield in gallons per minute.]

Rock.	Location.	Relation of average yield of wells in any location to average yield of all wells in same kind of rock.			Relation of average yield of wells in any location to average yield of all wells in same kind of location.		
		Average yield for location.	Average yield for rock type.	Difference.	Average yield for location.	Average yield for all in similar location.	Difference.
Granite	Hills	9.3	17.4	− 8.1	9.3	20.6	−11.3
	Slopes	10.3	17.4	− 7.1	10.3	8.7	+ 1.6
	Valleys	21.7	17.4	+ 4.3	21.7	24.4	− 2.7
Schist	Hills	26.5	17.0	+ 9.5	26.5	20.6	+ 5.9
	Slopes	4.7	17.0	−12.3	4.7	8.7	− 4
	Valleys	10.0	17.0	− 7	10	24.4	−14.4
Gneiss	Hills	21.8	17.0	+ 4.8	21.8	20.6	+ 1.2
	Slopes	10.1	17.0	− 6.9	10.1	8.7	+ 1.4
	Valleys	24.3	17.0	+ 7.3	24.3	24.4	− .1
Other crystalline rocks	Hills	24.7	26.4	−11.7	21.7	20.6	+ 1.1
	Slopes	2.2	26.4	−24.2	2.2	8.7	− 6.5
	Valleys	42.5	26.4	+16.1	42.5	24.4	+18.1

TABLE 5.—*Relation of level at which water stands in wells in various locations to surface of rock which marks bottom of overlying drift.*

Rock.	Location.	Percentage of wells in which water level is below rock surface.	Percentage of wells in which water level is above rock surface.	Percentage of wells in which water level is even with rock surface.
Granite	Hills	37	50	13
	Valleys	11	89	0
	Slopes	41	50	8
	Plains	50	50	0
Schist	Hills	62.5	37.5	0
	Valleys	0	100	0
	Slopes	50	33	17
Gneiss	Hills	69	21	10
	Valleys	22	78	0
	Slopes	44	36	20
	Plains	0	50	50
Granodiorite	Hills	71	0	29
	Valleys	0	100	0
	Slopes	60	40	0
	Plains	33	67	0

NOTE.—A summary of the results for all wells may be found on page 133.

TABLE 6.—*Average depth and yield of wells in varying rock types.*

Rock.	Depth of surface material.		Depth in rock.		Total depth.		Yield.	
	Feet.	Number of records.	Feet.	Number of records.	Feet.	Number of records.	Gallons per minute.	Number of records.
Granite	20.6	45	100.5	45	122.5	54	13.0	35
Gneiss	16.3	69	112.6	70	131.4	73	12.3	50
Schist (other than quartzite schist)	13.7	23	96.0	23	109.7	23	13.9	16
Granodiorite	24.1	15	138.5	15	156.6	19	33.0	13
Quartzite schist	32.5	3	411.0	3	443.5	3	7.25	3
Phyllite (slate)	14.4	5	80.2	5	93.8	5	Very poor.	5

TABLE 7.—*Average depth from surface to water level in the well.*

Location.	Depth to water.	Number of records.
	Feet.	
Hills	19	76
Valleys	11	30
Slopes	15	44
Plains	8	30

TABLE 8.—*Average depths, in feet, of surface material, of rock, and of the entire well for the records at hand, exclusive of wells more than 400 feet in depth and of wells known to be dry.*

Location.	Average depth of surface material.	Average depth in rock.	Average total depth.	Number of records.[a]
Valleys	36	104.5	140.5	26
Hills	17	94.0	111.0	67
Slopes	21	79.4	100.4	54
Plains	10	74.0	84.0	16

[a] Average depth of surface material based on only 122 records.

NOTE.—Average total depth of all these wells is 108.4 feet.

It is clearly shown in Table 1 that there is an increase in the average yield of wells with increase in depth to a certain point, beyond which the average yield tends to decrease, owing mainly to the larger proportionate number of the deep wells that prove to be failures. The table also indicates that most of the wells are between 30 and 200 feet in depth. The wells in granite are evenly distributed over a considerable range in depth, but most of the wells in gneiss are shallow, 70 per cent being less than 100 feet deep. The wells in granodiorite whose records are available are mostly in the schistose area near Stamford, and the data indicate that in this rock good supplies of water are obtained at considerable depth.

Table 8 indicates that the impression of well drillers that wells obtain water at shallower depths on hills than in valleys is borne out by the facts, but that the greater part of the difference is due to the heavier deposits of surficial drift in the valleys. On the other hand, it is shown in Table 3 that the average yield of wells in valleys is somewhat greater than that of wells on hills. If there were any relation between the yield of wells and their topographic situation it would seem that wells located on slopes should give an average yield intermediate between that of the wells on hills and that of the wells in valleys. On the contrary, the wells on slopes average a yield less than half of that for either of the other locations and the wells on slopes are also the shallowest of the three groups.

Table 5 shows that the ground water in wells in granite has an occurrence differing from that in the other rock types, the position of the water level with reference to the rock surface being the reverse in wells on hills and slopes to that in the other rocks, though in the wells in valleys the same relation is shown by all rock types.

CHAPTER V.

GROUND WATER IN TRIASSIC SANDSTONES AND TRAPS.

INTRODUCTION.

The bed rock of Connecticut, as is shown on the map (fig. 11), consists of two main types, widely separated in character and age—the pre-Triassic metamorphic crystalline rock and the Triassic sandstone, conglomerate, shale, and lava. In the sedimentary rocks and traps of the Triassic area the water occurs in four situations—within the rocks themselves, in bedding planes, in joints, and along fault lines.

WATER WITHIN THE ROCKS.

CONDITIONS OF OCCURRENCE.

No rock is so dense as to exclude water entirely. However firm and compact it may appear to be, there are spaces between the individual grains and crystals, of capillary size and larger, which, though invisible, allow access and movement of water. Though it is true that all rocks possess a capacity to hold water, yet the amount of available space varies within wide limits, in accordance with the character of the rock. In the crystalline rocks, composed of closely interlocking crystals, there is small space for water, and the densest known granite (from Montello, Wis.) has an average porosity of only 0.237 per cent, or about 1 part in 400. In sand the pores may constitute 30 to 40 per cent of the volume; in sandstone, 20 per cent or more. The sedimentary formations of Triassic age in Connecticut include sandstone, conglomerate, and shale, all of which have relatively large water capacity.

WATER IN SANDSTONE.

The prevailing sedimentary rock in Connecticut is sandstone, which varies in texture from coarse to fine and in color from chocolate brown to reddish brown, with local green and buff tints. Commercially the rock is known as "brownstone," and the quarries of Portland, Long Meadow, and other places have furnished a great amount of it for building purposes. The large outcrops of sandstone in Connecticut are generally not homogeneous, presenting as a rule wide variation in grain, conformity, order of stratification, and relative amounts of the component strata. Overlapping lenses of sand-

stone, conglomerate, and shale, rather than uniform beds of sandstone, make up the formation. In one of the quarry pits at Portland four types of rock are sufficiently distinct to be separated for commercial purposes.

The Triassic sandstone of Connecticut consists of quartz, feldspar (in many localities kaolinized), biotite, muscovite, and garnet, with fragments of chlorite schist, mica schist, gneiss, and granite. The cement which holds the grains together and gives color to the rock is partly a film of iron oxide surrounding the grains and partly fine clay.

Sandstone in general has great water-holding capacity, and the Connecticut varieties form no exception. A sample from the Portland quarry which was dried carefully and then immersed in water for three months was found to have increased in weight during that time from 150 to 154 pounds,[a] an absorptive ratio of about one-fortieth of the weight of the specimen examined. The amount of water absorbed was about 2 quarts for every cubic foot, equivalent to 88,502,857 barrels for a square mile of rock 200 feet deep. This is sufficient water to form a lake 1 mile in diameter and 50 feet deep.

In spite of its capacity for holding such enormous quantities of water, the exposed portions of the sandstone usually appear dry. In railroad cuts and on cliffs the water is not seen to ooze out of the rock nor to form a film over its surface. It is only in artificial openings, such as wells, that the water drips from the rock itself. This absence of water on the face of a natural rock outcrop does not indicate that the rock is not saturated at a short distance back of the face, for the water within the rock would naturally seek a lower level of escape through some bedding plane or fracture nearer the base of the hill. In several localities springs issue from crevices immediately above which the rock is practically dry. In such localities the water table is depressed at the point of leakage.[b] (See fig. 15.) The depth to which saturated sandstone extends varies with the topographic location and character of the rock, but is in few places more than a few hundred feet. Wells are reported where the rock was so dry between depths of 200 and 300 feet that water had to be pumped into the hole to enable the drill to perform its work.

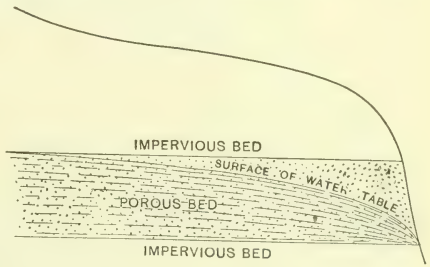


FIGURE 15.—Diagram illustrating depression of water surface at point of leakage in sandstone.

[a] Stone, vol. 9, 1894, p. 20.

[b] Fuller, M. L., Water-Supply Paper U. S. Geol. Survey No. 110, 1905, p. 98.

WATER IN CONGLOMERATE.

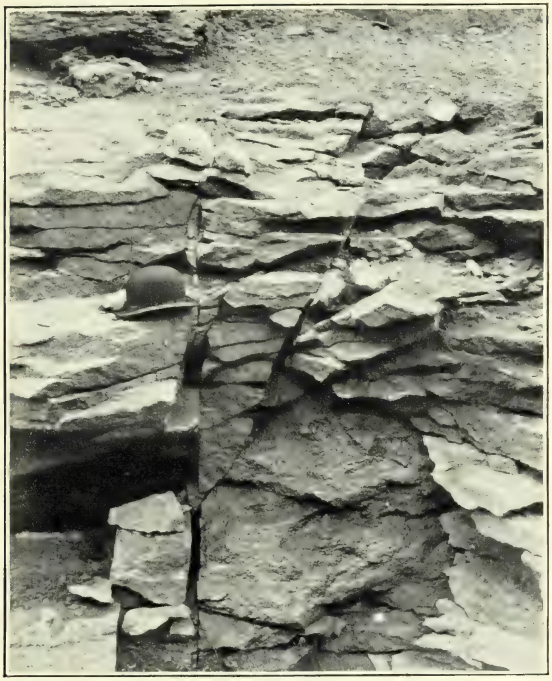
Interbedded with the sandstones are lenses and short layers of conglomerate, and at several localities, as in the vicinity of New Haven and elsewhere along the Triassic border, this rock occurs in great abundance. The pebbles in the conglomerate average from 1 to 5 inches in diameter, but reach extremes of more than 2 feet. Conglomerate is cemented gravel, and the pebbles of which the Triassic conglomerate of Connecticut is composed are crystals of quartz, feldspar, and mica, together with partly rounded fragments of schist, gneiss, porphyries, granite, and pegmatite. The pebbles, large and small, lie in a matrix of sandstone. The cementing material and coloring matter are identical with those of the sandstones, except that there is perhaps a smaller amount of clay.

The conglomerate contains within itself abundant water, as its pore space is relatively large, but, like the sandstone, it seems to give up its water readily to joints and other large openings and to be relatively dry at great depths. The deep wells in the Connecticut Triassic area which have been failures—the Northampton well, 3,700 feet deep; the Westfield well, 1,100 feet; the Forestville well, 1,290 feet; and the Winchester Arms Company well at New Haven, 4,000 feet—are in the conglomerate. The easterly dip of the conglomerate along the west side of the Triassic area suggests conditions favorable for flowing wells, especially as the upturned edges of the strata are in a position to receive the water from the Western Highlands and to carry it eastward into the ground. These favorable conditions are, however, offset by the lack of continuity in the rock strata due to the presence of joints and faults. (See pp. 133–135.)

WATER IN SHALES.

The shales of the Connecticut Valley, popularly called "slate," do not cover wide areas to the exclusion of other rocks, but occur as beds or lentils interstratified with the sandstones, conglomerates, and lavas which make up the Triassic of the State. Typical shales are layers of mud that have become consolidated by the addition of cementing material and by the pressure of overlying rock masses. The fragments of which they are composed are largely grains of quartz, feldspar, and mica, either fresh or partly disintegrated, and the layers into which a shale outcrop is divided are usually but a fraction of an inch thick.

Pure mud shales contain a large amount of water, but the pore spaces are so small that they retain it with great tenacity and wells sunk in unbroken shale beds of homogeneous structure remain as holes with moistened sides but with an amount of water insufficient for practical purposes. The Triassic shales, however, are not homo-



A. VERTICAL AND HORIZONTAL JOINTS IN SANDSTONE.

B. VERTICAL AND HORIZONTAL JOINTS IN TRAP.

geneous layers of compressed mud and silt, but thin beds of shale alternating with sandstone, and much rock which passes for shale or "slate" is in reality a very fine grained sandstone of large water capacity. Furthermore, the shale contains some small lenses of lime and gypsum, possibly also salt, which are readily dissolved and leave channels and pipes through which ground water may circulate with great freedom. The shales are furthermore broken by joints and faults of sufficient extent to permit the passage of water. These characteristics make the Triassic shales of scarcely less value than the sandstone as sources of water, although the quality of the water is usually inferior. The chief importance of clay shales, however, is not as a water carrier, but as a confining layer in the midst of more porous material which serves to collect and transmit the water, giving rise to springs and determining favorable locations for wells. (See p. 109.)

WATER IN TRAP.

There are two chief types of trap rocks in the Connecticut Valley—extrusive volcanic rocks (basalt) and intrusive rocks (diabase)—but considered in regard to their water-bearing capacity they may be treated as one. Except for the amygdaloid cavities in the lavas, filled with fresh or decomposed calcite, zeolites, etc., the traps are exceedingly dense, and the interlocked crystals of feldspar and pyroxene afford practically no access to surface waters. That ground water does not penetrate these rocks is clearly shown by the presence of unaltered anhydrite and bitumen at depths less than 30 feet from the surface. Moreover, the topographic form of the trap ridges prevents their absorption of surface waters. They project high above the surrounding plain and slope in two directions, and the rain that falls on them is hurried to the lowlands in streams. In fact, the lower slopes of the lava ridges furnish favorable catchment areas for surface waters, which are utilized by Hartford, New Britain, Meriden, and New Haven for city water supplies. Under the most favorable conditions the traps contain within themselves probably less than one-half of 1 per cent of their weight of water, and therefore may be disregarded as water reservoirs. (See Pl. IV, *B*.)

WATER IN BEDDING PLANES.

CONDITIONS OF OCCURRENCE.

The sandstone, conglomerate, and shale of Connecticut, although differing markedly in texture, in extent and uniformity of bedding, and in structural relations, are alike in being water-laid deposits. They constitute a series of parallel strata separated by more or less definite bedding planes, whose location, extent, and character exert a predominant influence on the water supply of the State. If the

strata composing the Triassic were all of one type and homogeneous the ground water would be uniformly distributed, but owing to the different degrees of permeability possessed by the sandstone and shale the water tends to concentrate along definite horizons. For example, a bed of impervious shale overlain by sandstone allows water to accumulate in the upper strata. The water occupying the spaces between the sandstone grains will find it easier to move along the bedding plane than to penetrate the shale, and if the plane is exposed on a hillside or in an artificial opening a stream or seepage of water will likely be developed. (See fig. 5.) Shale is the most impervious rock in the sedimentary series and sandstone the most pervious, and together they form the best reservoirs, but water will occupy the bedding plane between sandstone and lava, or between sandstone and conglomerate, or between two beds of the same strata. The bedding planes are not usually actual cavities visible to the eye, but rather planes of parting through which water moves by capillarity. In some places, however, the solvent action of water operating for thousands of years has widened the cracks to a fraction of an inch, and in a very few localities definite stream channels several inches in height have been developed through which water pours as small-sized rills.

That water occupies these bedding planes in large amount is abundantly shown by direct observation and by the experience of well drillers. In one of the Portland quarries, where pits 200 feet in depth have been opened "water everywhere emerges from along the bedding planes, especially along the shaly partings, where, dripping down, it darkens the quarry walls over large surfaces."[a] In 1906 an exposed rock wall 75 feet in height in this quarry showed water entering from the bedding planes in large amounts, but none coming from the joints or oozing from the rock surface. In dozens of springs within the sandstone area the water issues from the contact between strata of varying texture and composition.

The experience of well drillers leads to the same conclusion. C. L. Wright, of Augurville, who has sunk many wells in the sandstone, finds that the water comes from "flat seams"—that is, bedding planes at the "juncture of firmer rocks overlain by loose-textured rocks"—and that water frequently passes from these planes as a "sheet extending entirely across the drill hole." A. A. Murray, of Middletown, reports that the largest amount of water "is to be encountered in hard rock directly at its contact with shale." In the vicinity of Hartford, according to C. L. Grant, the "usual water horizon is in the sandstone directly above the shale."

That water circulates freely along definite bedding planes is shown by the manner in which wells that are located in proximity tend to influence one another. For example, five wells of the Electric Light

[a] Stone, vol. 9, 1898, pp. 42–43.

Company in Hartford, sunk in sandstone and shale to a depth of 200 to 225 feet and situated 40 to 50 feet apart, are all affected when water is pumped from any one, apparently because they draw their water from the same bedding plane. Other interesting evidence of the presence of water in bedding planes and its movements along these planes is furnished by two wells at the sanitarium 2½ miles northwest of Wallingford. One of the wells became contaminated by gasoline from a buried tank, and shortly afterward the other, 225 feet distant in the direction of the slope of the rock, became contaminated also. The polluted water had apparently traveled down the tilted bedding plane between sandstone layers.

Another proof of the circulation of water along bedding planes is found in the fact that the rock bounding these planes is decomposed by the action of chemicals carried by subterranean waters. In quarries and railroad cuts where these bedding planes are exposed they usually appear as lines or zones of discolored rock, but in many places there is a distinct layer of leached and disintegrated material that has formed in place by slowly moving ground water charged with carbon dioxide and other chemical reagents.

BLACK SHALE.

Probably the most impervious rock within the Triassic area is the black bituminous shale which occurs as a member of the "Posterior" sandstones. (See p. 39.) In the vicinity of Hartford this shale has been penetrated by wells at a number of localities and at different depths, and it rarely fails to define a water horizon of great importance. The logs of wells shown in figures 16 and 17 were furnished mainly by C. L. Grant and demonstrate two interesting facts—(1) that the water-bearing strata may be shale, as in the Newington, Allyn House, and Goodwin Park wells; or sandstone, as in the Bloomfield wells; or conglomerate, as in the Windsor street well; and (2) that the typical posterior black shale, unmixed with sandy layers, is a water-confining bed of exceptional impermeability, even where only 10 feet in thickness. The well of F. C. Dininy obtains its principal water supply at 256 feet below the surface and little water was encountered at a greater depth.

WATER IN JOINTS.

VERTICAL AND HORIZONTAL JOINTS.

As explained on pages 37–38, all rocks are traversed at relatively short intervals by cracks or seams which serve to mark the rock surface into polygons and break it up into blocks of various sizes. These are the joints in rocks, and their presence and distribution are important factors bearing on the water supply of Connecticut.

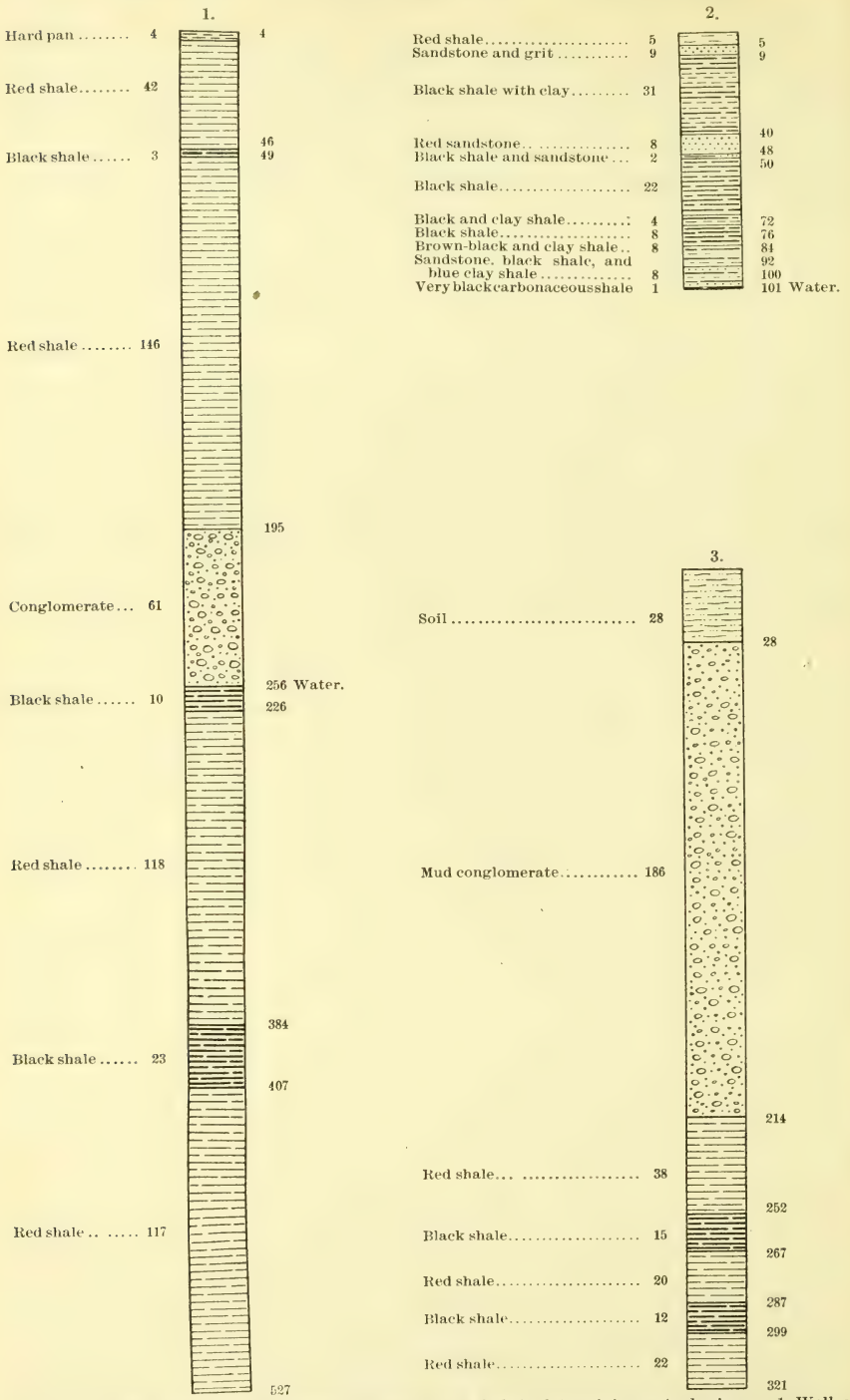


FIGURE 16.—Well logs showing influence of Triassic black shale in determining water horizons. 1, Well of F. C. Dininy, Windsor street, Hartford; water stands at 95 feet when well is pumped; yields 40 gallons a minute at 150 feet. 2, Well of H. C. Douglass, Bloomfield; flows 2 feet above surface; data furnished by owner. 3, Allyn House well, Hartford.

The joints in Triassic sandstone, conglomerate, and shale intersect at various angles, both in the vertical and in the horizontal plane, and many of the blocks which they bound are wedges of large or small size. Numerous measurements of the inclination of joint planes show that they stand commonly at high angles approaching the vertical. In the Fairhaven tunnel the prominent joints dip between 65° and 86° S. In the railroad cut north of Yalesville and in several other localities the dip of the main joints is less than 10° from the vertical. Approximately three-fourths of the conspicuous joint planes noticed at sixteen localities in Triassic sedimentary

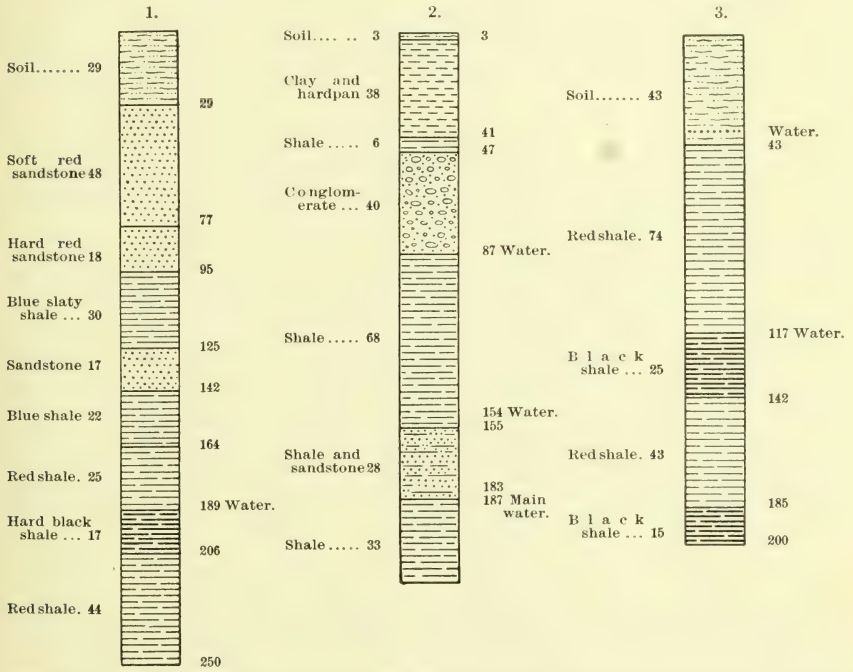


FIGURE 17.—Well logs showing influence of Triassic black shale in determining water horizons. 1, Flowing well at Goodwin Park, Hartford. 2, Well of L. A. Storrs, Bloomfield. 3, Well of Dr. A. B. Johnson, Newington; yields 40 gallons a minute.

rocks are between 70° and 90° from the horizontal. There are, however, numerous fractures which are nearly or quite parallel to the planes of stratification and which serve to break the rock into still more irregular and indeterminate fragments. These horizontal joints are in many places approximately parallel to the surface of the ground, and where they cross the bedding planes it is usually at an angle of less than 25°.

Joints, both vertical and horizontal, are more common and more conspicuous and intersect at a larger number of angles in conglomerate and coarse sandstone than in shales. In fact, large regular blocks of conglomerate are quarried in very few places within the State.

In the sandstone quarries the joints are fairly regular and evenly spaced. In the long exposure of shaly sandstone in the gorge at South Meriden vertical joints are rare. Near Mill Rock joints in fine sandstone start, branch, and die out within a few inches, and in a number of localities joints traversing sandstone and conglomerate stop abruptly on reaching a stratum of shale. (See below.)

DIRECTION AND CONTINUITY OF JOINTING.

In the Portland quarry the prominent joints run N. 50° E., N. 60° E., N. 75°–85° E., and N. 20° W.; in the vicinity of New Haven the chief joints extend east and west, N. 70°–80° W., N. 20° W., N. 15°–20° E., and N. 50° E.; at West Granby, N. 80° W., N. 35° W., N. 10° E., and N. 20° E.; at West Cheshire, N. 80° W., N. 50°–60° W., N. 30° W., N. 10° E., and N. 55°–60° E. In the Pomperaug Valley Hobbs[a] found four major directions of jointing—N. 34° W., N. 5° W., N. 15° E., and N. 54° E. Although these uniform joint directions indicate some cause operating throughout the Triassic areas, there are many local variations, and in each region prominent cracks occur which do not correspond with the more common joints. For practical purposes each locality must be studied separately.

Some of the more prominent joint planes have been traced on the surface for several hundred feet and from the top to the bottom of the deepest quarry and railroad cuts. A few doubtless extend parallel to fault lines for some thousands of feet. Most of the joints observed, however, appear as open cracks for distances rarely exceeding 50 feet, though they may extend for great distances, both vertically and horizontally, as invisible parting planes.

SPACING OF JOINTS.

In the outcrops of sedimentary rock examined there was found great irregularity in the number and distribution of joints. In places the joints are 50 to 60 feet apart; elsewhere ten to twenty joints occupy 50 feet of wall space. In most large outcrops there are zones along which joints are crowded at intervals of less than an inch, and on weathered surfaces and in cuts where blasting has been carried on the rock is shattered into fragments a few inches in thickness by a multitude of intersecting joints. Outcrops of red and black shale occur in which the horizontal joints have separated the rock into chips or flakes that could be removed with a shovel. It is evident that in such rock ground water would circulate freely and be stored in large quantities. In the Portland quarries the main sets of vertical joints are 30 feet or more apart; at the north end they are 35 to 100 feet apart; and nowhere in the quarry were joints of the

[a] Hobbs, W. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, p. 100.

same series observed nearer than 7 feet from each other. In the railroad tunnel at Fairhaven the larger joints are about 25 feet apart and converge at low acute angles and branch out. At Pine Rock and West Rock the joints of all kinds average about five to a linear yard. The spacing of joints and their angle of inclination are the factors which determine the number contributory to a well.

Both vertical and horizontal joints are wider, more numerous, and more closely spaced near the surface than farther down. In one quarry observed by the writer the upper 30 feet of wall had nearly twice as many horizontal joints as the second 30 feet. The effect of joints is to greatly favor the absorption of water, but this must be a surface phenomenon, as the joints die out with increasing depth. In Connecticut large open joints are probably rare at depths exceeding 200 feet.

OPENING OF JOINTS.

Some joints at the earth's surface and probably all joints at considerable depths are tightly closed and are more nearly planes along which the rock might be broken than open cracks. Many joints, however, are a fraction of an inch wide, some are 1 inch to 2 inches wide, and in the Blakeslee quarry horizontal joint zones 3 to 4 inches wide are found. One crack in this quarry which is $2\frac{1}{2}$ inches in width at the top was so narrow at the bottom that a sheet of note paper could not be inserted. Many joints exposed in quarry walls are filled with decomposed rock through their extent, and experience in well drilling proves that decomposition extends to considerable distances and serves to enlarge cracks to an important degree. (See pp. 73–74.) Where two joints intersect or where one crosses a bedding plane a channel may be developed by removing the disintegrated rock which forms the boundary planes. (See fig. 18.) In one of the Portland quarries the water enters in good-sized streams from vertical joints to an amount estimated at 250,000 gallons daily. Such freedom of circulation would account for the water-laid sand found in joints at Hartford 20 feet below the surface. Numerous small joints, however, furnish more abundant and uniform water supply than a few large open fractures.

JOINTS IN TRAP.

The direction, continuity, and inclination of cracks in the trap of the Triassic area are essentially the same as in sandstone. Exposures of trap rock are invariably characterized by well-developed vertical joints intersecting one another in all directions in vertical planes and dividing the rock into a series of polygonal blocks. This type of jointing undoubtedly is more conspicuous in exposures than it would be in unweathered ledges, yet the structure is developed in

deeply buried rock and occasions trouble in drilling, owing to the breaking off of angular blocks that wedge the tools.

The opening of joints in trap and their value as reservoirs are practically the same as in the denser crystalline rocks described in Chapter IV (pp. 54–103).

WATER ALONG FAULT LINES.

Faults in rock are joints or cracks along which the strata have moved up or down or sidewise. The amount of displacement may be a fraction of an inch or thousands of feet, but as a rule there is a complete break in the continuity of the strata and a more or less open crack to mark the line of rupture. Few faults are single clean-cut breaks; more commonly they consist of a number of breaks that

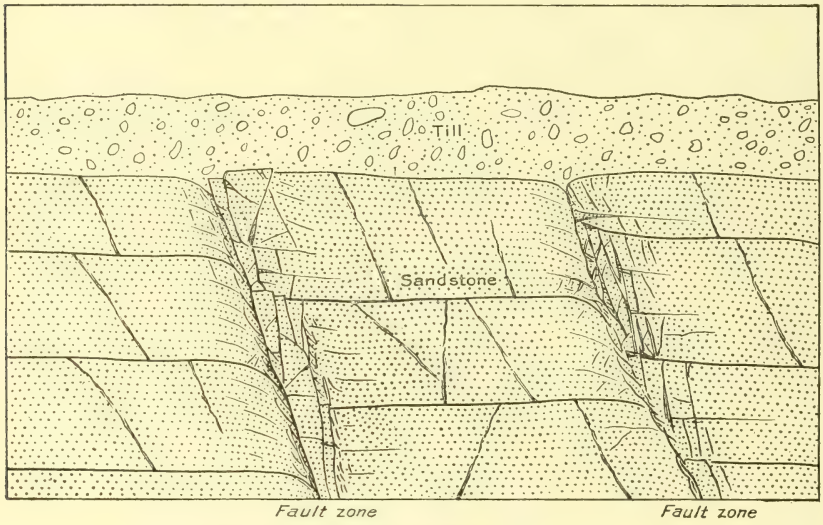


FIGURE 18.—Sketch showing fault zones in sandstone.

result in shattering the rock along a line some feet in width, forming a zone of material arranged as a confused mosaic of loose or cemented fragments.

The structure of fault zones is favorable for the absorption of large quantities of ground water, which may be readily recovered. (See fig. 18.) Many springs in Oregon, the hot springs of the southern Appalachians, Saratoga Springs, etc., are located along faults, and the character of their waters is due to the great depths from which they come. The relation of springs to fault lines is a well-known phenomenon in Connecticut and some striking instances have been described by W. H. Hobbs.[a] At one place in the Pomperaug Valley eight springs occur within a distance of 60 rods, all located on a single

[a] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, pp. 91–93.

fault line. Near South Britain a number of springs are located at the intersection of two or more fault lines.[a] Where fault lines are exposed in cuts and quarries the circulation of water in them is shown by actual seepage, by growth of plants, and by a zone of decomposed rock, formed by the solvent and oxidizing power of the ground water carrying carbon dioxide, etc., in solution. The relation of faults to water supply is well illustrated in the Middlesex quarry. Here the principal water carrier is an oblique fault zone 6 inches to 1 foot wide, which not only absorbs much water from the earth's surface but is also the main artery receiving supplies from bedding planes one-fourth to one-half inch wide. This fault contains probably 15 per cent of open space available for water storage.

Examples of wells located on faults are those of the Hartford Light and Power Company and of Armour & Co. at Hartford. The wells at the New York, New Haven and Hartford power house and the Berlin Brick Company and the Yale Brick Company's works, Berlin Junction, and at Hotel Russwin, New Britain, are advantageously located near fault zones.

RECORDS OF WELLS IN TRIASSIC SANDSTONES, CONGLOMERATES, AND SHALES.

The records of wells on the following pages have been selected to show the conditions controlling the recovery of ground water in the Triassic sediments of Connecticut.

[a] Water-Supply Paper U. S. Geol. Survey No. 67, 1902, p. 80.

Records of wells in sandstone and other Triassic rocks of Connecticut.

No.[a]	Town.	Village.	Owner.	Topographic position.	Depth to rock.	Depth in rock.	Depth of well.	Depth to principal source.	Depth at which water stands.	Variation of water level.	Yield per minute.	Diameter of well.	Temperature.	Character of water.	Use.	Cost per foot.	Remarks.
					Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*		*Galls.*	*In.*	°*F.*			*Dolls*	
*1	Avon		Mrs. J. B. Hadsell.	Plain	70	30	100	75	23	Pumping lowers.	1	6	....	Hard	Domestic	.....	
2	Berlin		C. M. Jarvis				224		46		Good.	6	....	...do	...do	2.35	Watercomesfrom shale.
3	...do		G. H. Sage	Hill	75	75	150	148	50			6	....	...do	...do	2.75	
4	...do		J. B. Smith				201		50		6	6	....	...do	...do	2.00	
5	...do	Berlin	F. L. Wilcox				220	220	50		40	8	....		General	3.40	
6	...do		Geo. Arthur	Hill	60	55	115		20		10		....		...do	2.00	
7	Bristol	Forestville	M. McCormick	...do	4	47	51		26		1		....		...do	2.50	
8	Bloomfield		H. C. Douglas	Slope	5	96	101		+ 2		8	6	....	Hard	Medicinal	.....	Flowing well. Water comes from black shale. (See analysis, p. 177.)
9	Chatham	East Hampton	F. S. Hall		22	14	36	28	22		¾	6	....	...do	Domestic	3.30	
10	Cheshire		Cheshire Coal and Feed Co.		35	7	42	42	14		60	6	....	...do		2.30	Probably from surface material at contact with rock.
11	...do		R. H. Morgan	Slope	11	180	191		17		4	6	52	...do	Greenhouses, domestic.	2.15	
*12	...do		S. A. Bronson		12	313	325		35		25	6	....			.....	
13	...do		Frank Ives		12	24	36	33	2		20	6	....			.....	
14	...do		Mr. Williams		5	83	88	35 40 85	8		6	6	....			.....	
15	...do	West Cheshire.	Ball and Socket Manufacturing Co.	Valley	....	....	150	146	19	Not lowered at 30 gallons.	+30	6	55		Factory, boiler.	2.00	Water found in "gray" rock. (See analysis, p. 177.)
16	Durham	Durham Center.	Henry Burchel	Slope	18	40	58	43	8	Pumping lowers and lower in summer.		6	....	Hard	Domestic	.....	Water comes from seam in rock.
17	...do		Albert Eich	Stream bed.	....	....	980?	.....	Flows.					...do	Domestic, stock.	.....	When allowed to flow this well dries up three other wells within a quarter-mile radius.
18	East Hartford.	Burnside	Mr. Hanson	Flat	15	33	48	.....	15		12	....	....		General	2.25	
19	...do	...do	J. M. Mohrs	...do	17	34	51	.....	15		2	....	....		...do	2.20	
20	...do	...do	P. Donohue	...do	30	46	76	.....	31		60	....	....		...do	2.00	

21	.....do.....	.....do.....	East Hartford Manufacturing Co.	.....	.....	.....	398	.....	Flows.	.....	Very large.	.....	.....	Hard....	.....	.....	
22	East Haven...	.....	G. E. Poirot.....	Hill...	½	99½	100	.....	28	.....	2½	.....	.....	.....	Domestic..	.....	Passes through trap rock.
23	.....do.....	.....	C. M. Finch.....	Slope..	7	48	55	50	15	.....	6½	.....	.....	.....	...do.....	.....	
*24	.....do.....	Morris Cove...	Rev. W. Roberts	Hill...	17½	54	71½	.....	22	.....	2½	.....	.....	Medium.	...do.....	.....	
25	East Windsor.	Broadbrook...	Jos. Morton	Flat...	60	26	86	.....	48	.....	32	.....	.....	.....	General....	.....	
*26	.....do.....	Melrose.....	F. Gowdy.....	Hollow	60	250	310	.....	4	.....	80	.....	.....	.....	...do.....	2.00	See analysis, p. 177.
27	.....do.....	.....do.....	E. M. Granger..	.....	135	135	270	.....	80	.....	22	.....	.....	.....	.....	2.00	
28	.....do.....	Warehouse Point.	Biard Daniels Co.	Flat...	17	385	402	.....	10	.....	120	.....	.....	.....	.....	1.75	
29	.....do.....	Windsorville..	Edw. Miller.....	Hill...	9	209	218	.....	43	.....	12	.....	.....	.....	General....	2.00	
30	.....do.....	.....do.....	John Colman.....	...do...	87	30	117	.....	47	.....	40	.....	.....	.....	.....	2.00	
31	Ellington.....	.....	John Thompson.	...do...	15	42	57	.....	11	.....	50	.....	.....	.....	.....	.....	
32	Enfield.....	Hazardville....	J. W. Copley....	Slope..	10	31	41	41	10	.....	40	6	47	Soft.....	Domestic, stock.	1.80	10 feet lower in summer of 1900.
33	.....do.....	.....do.....	E. C. Allen.....	.....	40	67	107	.....	20	Constant..	25	6	48	Hard....	Domestic..	2.00	
34	.....do.....	.....do.....	Wm. Smith.....	Plain..	52	58	110	108	28	.....	15	6	50	Soft.....	Domestic, stock.	.....	
35	.....do.....	.....do.....	Justin Bardwell.	...do...	15	26	41	.....	5	.....	28	6	.....	...do.....	General....	1.50	
36	.....do.....	.....do.....	E. King.....	Flat...	4	44	48	.....	5	.....	50	.....	.....	.....	...do.....	.....	
37	.....do.....	.....do.....	G. Reynolds.....	...do...	90	15	105	.....	15	.....	22	.....	.....	.....	.....	.....	
*38	.....do.....	Thompsonville.	Connecticut Valley Brewing Co.	.....	12	40	52	.....	7	Pumping lowers 8 feet.	31	6	51	Hard....	Boilers....	.....	
40	.....do.....	.....do.....	Issac Allen.....	.....	17	50	67	45,67	22	Lowers 15 feet in dry weather.	Good.	6	52	Medium.	Domestic..	.....	
41	.....do.....	Hazardville....	Frank Olmstead.	Flat...	38	67	105	.....	13	.....	15	.....	.....	.....	General....	.....	
42	.....do.....	.....do.....	Willis King.....	...do...	15	23	38	.....	23	.....	1	.....	.....	.....	...do.....	.....	
43	.....do.....	.....do.....	.....do.....	Hill...	40	33	73	.....	36	.....	6	.....	.....	.....	...do.....	.....	
44	.....do.....	.....do.....	Harry Bridge....	...do...	15	31	46	.....	12	.....	50	.....	.....	.....	.....	.....	
45	.....do.....	.....do.....	Mrs. M. Fox.....	...do...	17	32	49	.....	19	.....	29	.....	.....	.....	.....	.....	
46	.....do.....	.....do.....	Robt. Horthorn.	...do...	25	35	60	.....	10	.....	15	.....	.....	.....	.....	.....	
*47	Glastonbury..	.....	C. N. Carter.....	Valley.	150½	74½	225	210–225	30	Constant..	.....	2	....	Soft.....	Domestic..	.....	
48	Hamden.....	Mount Carmel.	H. D. Clark.....	Plain..	28	32	60	50	Flows, 2+.	Pumps down to 6 feet.	15	6	....	Medium.	...do.....	2.50	Well flows in wet seasons but not in dry.
49	.....do.....	.....do.....	A. Woodman....	.....	12	58	70	.....	14	.....	9	6	.....	.....	...do.....	.....	
50	.....do.....	.....do.....	F. S. Brockett...	Plain..	35	7	42	37	28	Constant..	15	6	42	Soft.....	...do.....	.....	Probably from gravel.
51	.....do.....	.....do.....	Phelps Montgomery.	Slope.	3	77	80	33 60 78	18	Pumping lowers to 26 feet.	15	.....	.....	.....	.....	.....	Sandy till and red sandstone to one-fourth mile south of a trap mountain.
52	.....do.....	.....	W. W. Terrell...	...do...	8	35	43	.....	15	Varies with wet and dry season.	.....	6	48	Hard....	Domestic..	2.00	
53	.....do.....	.....	I. V. Cook.....	Plain..	.....	.....	116	80	30	Constant..	.....	6	50	Soft.....	...do.....	1.50	

[a] Additional details concerning wells marked * are given on pp. 124–126.

Records of wells in sandstone and other Triassic rocks of Connecticut—Continued.

No.	Town.	Village.	Owner.	Topographic position.	Depth to rock.	Depth in rock.	Depth of well.	Depth to principal source.	Depth at which water stands.	Variation of water level.	Yield per minute.	Diameter of well.	Temperature.	Character of water.	Use.	Cost per foot.	Remarks.
					Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*		*Galls.*	*In.*	°*F.*			*Dolls*	
54	Hamden		W. C. Mansfield.	Slope			55	40	15	Varies with wet and dry season.	2			Hard	Domestic, barn.	2.00	
55	do		C. L. Wright	do	8	38	46	28	12		6			do	Domestic, lawn.	1.50	
56	do		B. A. Davis				140		17		Large.			do		2.00	
57	do	Whitneyville	Morris Steinert		4	119	123		20		10	6			Domestic		
58	do	do	F. D. Grave		0	140	140	130	34	Pumping lowers 20 feet.	15	a8			do		
59	do	do	W. F. Downes		7	43	50	35	3		5		6	Hard	General	2.50	Water destroys solder in copper tank.
60	do	do	H. R. Stadtmiller.	Slope	0	85	85		22	Pumping lowers to 40 feet.	8	6	45	do		5.00	
61	do	do	C. E. Langdon	Ridge	8	82	90	40	35	Varies 10 feet with dry and wet season.	6	6	45	Soft	Domestic		
62	do	do	New Haven Country Club.	Hill			196	190	30		Good	6		do	General	2.00	
63	do	do	F. D. Putnam	Slope	12	153	165	164	20	Constant	+15	6		do	House, barn.	3.00	
*64	Hartford		Mrs. Samuel Colt	do			1,250					6					
65	do		Hartford Rubber Works Co.	Valley	190	160	350		18	Constant	45	6	54	Hard	Drinking		
66	do		D. F. Burns	Slope	40	223	263	+200	Flows.	Pumping lowers.	30	6	53		Ice machine, general use.	2.00	
67	do		Y. M. C. A	Valley	52	148	200	175	50		+25	6					
68	do		Keney Park	Slope	58	142	200	166	Flows 9+.		14	6	51	Hard	Used to supply lake.	2.00	
69	do		Goodwin Park	Foot of hill.			251		Flows +31.		Flows $1\frac{1}{3}$.		53	do	Drinking	2.00	Water of black shale horizon. (See analysis, p. 177.)

70	....do....	.....	Joseph Dart.....	Hill...	....	....	74	69	Flows 0.	Constant..	Flows $\frac{3}{4}$.	....	....	Hard and sulphur.	Drinking, stock.	.....	
71	....do....	.....	Francis Parsons.	...do...	....	....	136	.....	86	.....	3	....	....	Hard....	Domestic..	2.25	
72	....do....	.....	J. A. Pilyard....	...do...	150	55	205	190	52	.....	60	....	....	Sulphur.	Manufacturing, bakery.	2.00	
73	....do....	.....	F. C. Rockwell..	.....	....	....	206	206	15	.....	.....	....	....	Hard....	.....	.....	
*74	....do....	.....	Capewell Horse-nail Co.	Plain..	12	238	250	.....	12	.....	.....	....	....	...do....	.....	1.60	See analyses, p. 177.
75	....do....	.....	H. C. Long.....	Hill...	15	26	41	.....	25	.....	23	....	50	.....	Domestic, stable.	3.00	
76	....do....	.....	Armour & Co....	Flat...	0	430	430	.....	1	.....	100	....	....	Hard....	Cooling....	.....	
77	....do....	.....	Kelly Bros.....	...do...	32	143	175	.....	15	.....	60	....	....	...do....	Washing stone.	.....	
78	....do....	.....	Atlantic Screw Co.	...do...	22	218	240	.....	12	.....	35	....	....	...do....	General....	.....	
*79	....do....	.....	Hartford Light and Power Co.	.....	....	....	620	.....	.....	.....	125	12	....	.....	.....	.....	
*80	....do....	.....	New England Brewing Co.	.....	....	....	462	.....	.....	.....	350	10	....	Hard....	.....	.....	
*81	....do....	.....	Armour & Co....	.....	....	....	420	.....	.....	Flows.....	150	6	....	.....	.....	.....	
*81½	....do....	.....	Hubert Fischer Brewing Co.	.....	....	....	500	.....	.....	.....	75	8	....	Hard....	Cooling....	.....	See note on p. 81.
82	....do....	.....	Brady Bros.....	.....	33	244	277	.....	.....	.....	25	6	....	.....	Bottling....	.....	Water becomes cloudy at times.
83	....do....	.....	W. C. Wade.....	.....	12	113	125	.....	13	.....	200	....	54	Hard....	Cooling....	.....	
84	Manchester....	South Manchester.	Harry Bowers...	Flat...	20	47	67	.....	21	.....	24	....	....	.....	General....	.....	
*85	....do....	....do....	Cheney Bros.....	Valley	12	445	457	400	Flows 15+.	Constant..	205	[b] 2	54	Hard....	Washing silks.	[c]	See analysis, p. 177.
86	....do....	....do....	M. S. Chapman..	.....	20	205	225	.....	Flow.	.....	30	6	....	...do....	Fish ponds.	.....	
87	....do....	....do....	.....do.....	.....	20	105	125	.....	Flow.	.....	11	....	....	...do....	...do.....	.....	
88	....do....	....do....	.....do.....	.....	20	55	75	.....	Flow.	.....	2½	....	....	...do....	...do.....	.....	
89	....do....	....do....	.....do.....	.....	20	55	75	.....	.....	.....	None.	....	....	...do....	...do.....	.....	
90	....do....	North Manchester.	F. J. Sharp.....	.....	19	81	100	.....	1	.....	10	....	....	...do....	.....	.....	
*91	....do....	....do....	American Writing Paper Co.	.....	....	....	300	.....	Flows.	.....	Flows, 12.	....	....	...do....	.....	.....	
92	....do....	.....	Clayton Grant..	Slope..	16	87	103	100	50	Constant..	.....	6	....	...do....	Drinking..	.....	
93	Meriden....	.....	H. L. Aubrey...	Plain..	....	....	100	35	20	.....	Large.	8	....	...do....	Laundry..	3.00	
94	....do....	.....	T. P. Lyon.....	...do...	30	46	76	70	6	.....	.....	6	....	.....	.....	2.50	
95	....do....	.....	Meriden Brewing Co.	.....	....	....	279	.....	18	.....	60	8	....	Hard....	Brewery...	.....	
96	....do....	.....	Meriden Bronze Co.	.....	....	....	300	.....	.....	.....	100	8	....	...do....	.....	.....	
97	....do....	.....	Foster-Merriam Co.	.....	100	200	300	.....	0	.....	100	8	....	.....	Factory...	.....	

[a] For 2 feet 6 inches.

[b] 8 inches for 385 feet; 6 inches for 75 feet.

[c] $3.50 for 8-inch; $2.75 for 6-inch.

Records of wells in sandstone and other Triassic rocks of Connecticut—Continued.

No.	Town.	Village.	Owner.	Topographic position.	Depth to rock.	Depth in rock.	Depth of well.	Depth to principal source.	Depth at which water stands.	Variation of water level.	Yield per minute.	Diameter of well.	Temperature.	Character of water.	Use.	Cost per foot.	Remarks.
					Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*		*Galls.*	*In.*	°*F.*			*Dolls*	
98	Meriden		J. G. Schwink, jr.	Slope			80		15	Constant	Large.	6		Hard	Stock	2.00	
99	do		D. L. Bishop	Flat			102	102	19		30	6		Soft	General	2.20	
*100	do	Meriden	Edward Miller & Co.				(*a*)				10–80	8		Hard	do		
*101	do	do	International Silver Co.		100	460	560		5			6		Very hard.	Too hard for boilers.		
102	do	do	Meriden Curtain Fixture Co.		50	255	305				25	6					
*103	Middlefield		G. W. Durkee	Hill	70	15	85	80	40	Pumping lowers 12 feet.	Large.	6	52	Soft	Domestic, stock.	2.00	
104	do		O. N. Miller	Plain	5	320	325		60			6		do	Domestic	2.25	
105	Middletown		A. W. Budde	Slope	40	70	110	70	35			6	50	Hard, iron.	do	1.50	
106	do		Connecticut Hospital for Insane.	Hill	70	138½	208½	190				4	45	Soft, iron	Drinking		
107	do		Goodyear Rubber Co.	Slope	40	156	196	130	Flows, 2+.	Pumping lowers.		6		Hard	Cooling		
108	do		Portland Silk Co.	Plain	50	71	121	120	Flows.			6				2.30	
109	do		Russell Manufacturing Co.	Stream bed.	30	120	150	130	Flows, 3+.		5	6		Soft	Drinking	2.00	
110	do		B. F. Turner	Terrace, plain.	25	35	70	70	20	Constant	Good.	5		do	Domestic	2.00	
111	do		R. Kennedy	do	50	200	250	240	10	Pumping lowers.	Good.	10		Iron		2.00	Water level sinks 2 or 3 inches in dry weather.
112	do		L. D. Brown & Son Co.	Slope	40	252	292		45	Pumping lowers 30 feet.	80	6		Hard	Drinking	2.00	See analysis, p. 177.
*113	do		Wilcox, Crittenden & Co.	do	15	785	800	40	12–25		(2)	6		Soft	Abandoned		
114	New Britain		A. J. Sloper	Hill			75	47	15	Constant	Small. 45	3		Medium			Became contaminated with use.
115	do		Landers, Tracy & Clark.	(*b*)	40	202	242	100	14	Pumping lowers	Large. 9	6		Hard			Water said to be in rock of slaty nature in trap.
*116	do	New Britain	Hotel Russwin				152		9		Large.						

117	New Haven		New England Dairy Co.			1	157½					6			General, boiler.		See analysis, p. 177.
118	do		Seamless Rubber Co.				160				10	8			Factory purposes, cooling, general.		
*119	do		Winchester Repeating Arms Co.				4,000				Dry.	8					
120	do		J. E. Heaton	Slope	0	101	101	4			1½	6			Domestic		
121	do		L. Simons		6	91	97		20		1	6			do		
122	do		H. B. Ives		26	59	85	1	12			6			do		
123	do		St. Francis Orphan Asylum.		6	236	242		3		3				General		
124	do		W. P. Blake	Slope	3	147	150		25		30	6			Domestic		
125	do		G. H. Gill		12	90	102		16		30+	6			do		
*126	do		Hoyt Beef Co	Flat	264	308	572		10		7	6			General		
127	do	New Haven	Lavigne Automatic Machine Co.			53	42	95			13	6					
128	do	Fair Haven	New Haven Iron and Steel Co.		119	406	525		10		1	6			General		
129	do		Housatonic Manufacturing Co.		32	168	200		25		10	6					
130	do	Fair Haven	J. R. King			203	203			Pumping does not lower.	40	6		Soft			No water above 100 feet.
131	do		Jos. Kegelmeyer	Plain	8	123	121	80	20		Good.	6				2.00	
132	do		Frank Brazos	do	70	57	127		48			6		Iron	Drinking	1.80	
133	Newington	Elm Hill	F. B. Wischek	Slope			75	17	13		3	6		Hard, iron.		2.00	
134	North Branford.	Northford	Mrs. T. H. Smith.	Hill			50	23	(c)			6				4.00	
135	do	do	Chas. Foote	Slope	1	99	100	98	(d)			6		Soft		2.00	
136	do	do					100					6					
137	North Haven	Montowese	T. Bishop		20	44	64		18		3	6					
138	do	do	do		20	62	62		18		2	6					
139	do		Wm. Dickerman	Hill	0	140	140		50		2½	6					
140	do		A. F. Austin	do	0	50	50	20	30			4		Hard	General		
141	do		do	do	4	50	54	44	10	Constant	Large.	6		do	do		
142	do		C. W. Turner	Slope			96	70	70		Good.		(e)		Domestic	2.00	
143	do	Clintonville	J. E. Brockett	Plain	30	59	89	79		Constant	Good.	6		Hard	Domestic, stock.	2.00	
144	do		M. N. Wooding	Hill	15	15	30	24	10	Varies in season.		6		do		2.00	
145	do		G. O. Munson	Slope			75	50	10	Constant		6		Soft	Domestic	1.50	
146	do		E. A. Potter	do	46	24	70							Hard	do	2.00	
147	do		H. R. Smith	Hill			140	130	10	Pumping lowers.		6			General	2.00	

a 5 wells, 250 feet. b Swampy ground. c Flows in wet season. d Varies seasonal, 20 to 45 e Top 50, bottom 50.

Records of wells in sandstone and other Triassic rocks of Connecticut—Continued.

No.	Town.	Village.	Owner.	Topographic position.	Depth to rock.	Depth in rock.	Depth of well.	Depth to principal source.	Depth at which water stands.	Variation of water level.	Yield per minute.	Diameter of well.	Temperature.	Character of water.	Use.	Cost per foot.	Remarks.
					Ft.	*Ft.*	*Ft.*	*Ft.*	*Ft.*		*Galls.*	*In.*	° *F.*			*Dolls*	
148	North Haven		I. L. Stiles & Son Brick Co.	Flat	50	70	120		30			6			General, boilers.		
149	Orange	West Haven	Mrs. E. Rogers	Hill	6	45	51				1½	6			Domestic		
150	Plainville		J. N. Bishop	Slope	6	46	52		40			6		Soft			
151	Rocky Hill		W. E. Pratt	Hill			56	54+½	28		1	6		Very hard.	Domestic	3.00	14 feet of soil, 36 feet of trap, 1½ feet of sedimentary rock.
152	Simsbury		Westminster School.	do			212		87	Constant	17	4	54	Soft	Drinking, washing, boilers.	3.00	See analysis, p. 177.
153	Somers	Somers Station	W. Prentice	Flat	52	18	70		30		50				General		
154	do	Somersville	Somerville Manufacturing Co.	do	60	26	86		20		20				do		
155	do	do	S. Anderson	do	83	11	94		20		7				do		
156	do	do	R. Delaney	Hill	55	15	70		37		2				do		
157	do	do	C. Doothy	do	20	13	33		10		5				do		
158	do	do	S. Ledgere	Flat	53	15	78		15		30				do		
159	do	do	S. Anderson	Hill	82	12	94		30		25				do		
160	do	do	W. Hemingway	Flat	13	29	42		18		50				do		
161	do	do	W. Billings	do	2	78	80		24		15				do		
162	Southington	Milldale	M. S. & C. T. Co.	Valley			200	150	20	Varies with season.		6		Hard	Boilers		
*163	South Windsor.	Wapping	C. M. Johnson	Flat	84	34	118	35	30		½	8		Soft	Domestic		
164	do	do	B. F. Nichols	Slope	60	20	80	80	36					Hard			
*165	Suffield		Suffield Water Co.	Hill	67	163	230	230	70		300	6	50	do	Town supply.		See analysis, p. 177.
*166	do		do	do	67	170	237	237	80			4		do	do		
167	do		Chas. Spencer	do	6	39	45		35		7				General		
168	do		Chas. Bissell	do	25	75	100		25		40				do		
169	do		S. A. Kent	do	90	169	259		18		100				do		
170	do	West Suffield	Terrett House	Flat	15	60	75		12		50				do		
171	do	do	Clara Loomis	do	5	120	125		17		8				do		
172	do	do	J. Gregg	do	8	123	131		24		10				do		
173	do	do	J. Noble	do	20	80	100		24		30				do		
174	do	do	W. Noble	do	3	59	62		24		14				do		
175	do	do	Sam Barr	do	50	50	100		20		40				do		
176	do	do	W. H. Hastings	do	135	50	185		Flows.		15				do		

177	....do....	....do....	Geo. Peckham	...do..	84	81	165	.....	13	.....	25	....	....	.....	...do.....	.....	
178	Wallingford...	.....	G. D. Hall.....	Slope..	.....	.....	67	.....	.....	.....	Small.	4	....	.....	Stock.....	.....	
179	....do....	.....	City of Meriden..	Plain..	.....	.....	105	80	80	.....	.....	6	....	.....	Domestic, stock.	2.50	
180	West Hartford.	Elmwood.....	N. E. Goodwin..	Hill...	55	45	100	30	30	.....	8	6	....	Hard....	Domestic..	3.00	
181	....do....	.....	Whitlock Coil Pipe Co.	Small hill.	60	137	197	.....	25	.....	.....	6	....	...do....	Boiler.....	.....	
182	....do....	.....	Paul Thompson.	Slope..	20	20	40	.....	30	.....	Good.	2	....	...do....	Domestic..	2.50	
183	....do....	.....	St. Mary's Home	...do ..	.....	.....	200	200	.....	.....	.....	.....	....	Soft.....	Stock,lawn	.....	
184	....do....	Buena Vista...	W. E. Howe.....	Hill...	.....	.....	62	.....	.....	.....	2	.....	....	Hard....	Domestic..	.....	
185	....do....	.....	H. O. Griswold..	.....	10	142	152	.....	15	Lowered pumping to 112 feet.	.....	6	....	.....	.....	.....	
186	Westersfield...	.....	C. L. Grant, C. I. Allen.	Hill...	.....	.....	192	.....	85	.....	7	6	....	Hard....	Stock.....	3.00	
187	....do....	.....	.L. Grant, E.S. Goodrich.	...do ..	.....	.....	82	.....	62	.....	12	6	.....	...do....	Domestic..	.....	
*188	Windsor.....	Rainbow.....	Wm. L. Bidwell.	Knoll .	70	61½	131½	.....	26	Pumping lowers.	½	6	50	...do.....	...do.....	.....	
189	....do....	.....	H. J. Fisk.....	Hill...	.....	.....	135	135	40	Constant..	2	6	.....	...do.....	General....	2.00	See analysis, p. 177.
*190	....do....	Windsor.....	Windsor Water Co.	.....	123	263	386	.....	40	Pumping lowers 5 feet.	30	6	....	.....	.....	.....	
*191	....do....	Wilson Station.	Christianson Bros.	.....	.....	.....	113	.....	.....	.....	50	6	....	.....	.....	.....	
192	....do....	Windsor Heights.	Dr. H. J. Fisk....	.....	.....	.....	135	.....	.....	.....	Small.	.....	.....	Medium hard.	.....	.....	
193	Windsor Locks.	.....	J. O. R. Sheridan.	Hill...	90	110	200	.....	30	.....	45	....	....	.....	General....	2.00	

NOTES.[a]

1. Passed through 20 feet of gravel, 25 feet of quicksand, 25 feet of gravel and hardpan, and 30 feet of red shale, in which the water was obtained. The water comes in slowly and carries fine sediment.

12. A little water was obtained at a depth of 50 feet and the water rose within 12 feet of the surface and remained at this level until a large supply was struck at a depth of 325 feet, when the water level lowered to 35 feet below the surface.

24. Passed through 17½ feet of soil and through 54 feet of trap ending in a hard red rock, probably sandstone. The source of the water is at the contact between the trap and the sandstone.

26. This well was drilled through sandstone into trap rock and the water enters above the trap.

38. This well is 52 feet deep and 6 inches in diameter, 40 feet of its depth being in the rock. The water rises within 7 feet of the top, a good many feet above the level of Connecticut River, which is only a stone's throw away. The pump raises 31 gallons a minute, which lowers the well 8 feet, but no farther. The water is moderately hard, has been used in boilers, and keeps a uniform temperature of 51° F. the year round.

47. Soil and sand, 20 feet; blue clay, hard and dry, 30 feet; clay and red quicksand, 10 feet; fine red quicksand, very shifting and hard packed, with a thin layer of saturated gravel at 118 feet from the surface, 60 feet; quicksand, 30 feet; gravel, 8 inches; sandstone, varying in hardness at different depths, 74½ feet. The water stood at 8 feet below the surface in the first soil and sand stratum but dropped to 30 feet below the surface after the 30-foot layer of clay was penetrated.

64. This well was drilled in 1863 by Col. Samuel Colt and flowed until 1898, when a well was drilled 1,000 feet farther north and the Colt well stopped flowing the next day.

74. This well was drilled by C. L. Grant, who furnished the following data: Depth, 250 feet; diameter, 8 inches. The well is in rock and flows. Elisha Gregory, a well driller of New York City, states in his "Torpedo circular" that the well was torpedoed by him at a later date and that as a result the yield was increased from 15 to 35 gallons a minute. It is reported that the quality of the water was injured by the process. Inquiry at the office of the company shows that at last accounts the water was not used for anything, so heavily is it charged with mineral matter. For analysis see table on page 177.

79. The 620-foot well of this company gives a more copious supply of water in rainy than in dry weather. The water contains too much calcium sulphate for boilers but is used for condensers. This well is said to have diminished the yields of four wells, each about 200 feet in depth, sunk for the same company.

80. It is stated that 400 gallons a minute have been pumped from this well without making any apparent impression on the water level. The well is 462 feet deep.

81. Depth, 420 feet. The water flows 1 inch over the top of the pipe when allowed to stand, which brings the water level above a large part of the neighboring land. The ordinary yield is 150 gallons a minute, the well being pumped continuously.

†**81½.** Depth, 500 feet; diameter, 8 inches. The water rises to the surface of the engine-room floor, and is pumped at the rate of 75 gallons a minute. The well is drilled in the "Upper" sandstones, but unquestionably pierces the "Posterior" trap sheet, which outcrops at no great distance to the west.

85. The water in this 457-foot well will rise 15 feet above the top and yield 205 gallons a minute at the surface. Pumping 600 gallons a minute for ten hours lowered the water level to 12 feet below the surface, where it remained constant.

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[a] Descriptions of wells marked "†" are taken from Water-Supply Paper 110.

†**91.** Depth, 300 feet; diameter, 4 (?) inches. The water flows over the top of the pipe at a rate of probably 10 to 12 gallons a minute. The water is hard and is used for drinking purposes only. The well lies entirely in the rock, which, in the stream near by, is seen to be rather loose in texture and to be filled with fragments of the crystalline rocks of the neighboring eastern highland.

†**100.** There are on the premises of this company five artesian wells, all 8 inches in diameter, from 250 to 300 feet deep, and bored into red sandstone, which at this place lies from 6 to 10 feet below the surface of the ground. The yield was measured when they were first bored, and varied in the different wells from 10 to 80 gallons a minute. The supply thus measured was obtained by means of an ordinary suction pump, which, operated at the rate named, lowered the water about 25 feet below the surface—as low as it could be pumped with that form of apparatus. A few years ago a system that works by compressed air and forces the water from depths of 70 to 90 feet was installed. This apparatus gave a very greatly increased output, which now supplies all the needs of the company. The water from these wells is all discharged into one large cistern, from which it is circulated through the factory. It is not easy to determine exactly the amount of water used, but it is estimated as between 75,000 and 100,000 gallons a day of ten hours. A much larger quantity than this could be obtained if needed. The water is satisfactory for manufacturing purposes except for use in boilers.

101. A well 560 feet deep, penetrating 9 feet of soil, 18 inches of gravel, 90 feet of quicksand, and 459½ feet of rock.

103. Drilled through 24 feet of clay, 20 feet of sand, 8 feet of clay, 50 feet of sandstone.

113. Depth, 500 feet. At a depth of 40 feet in sandy shale the well gave a small flow and drained an old dug well, 25 feet deep, in similar material. The well passed through about 300 feet of sandstone above bluish sandy shale and through a soft carbonaceous shale at about 400 feet. The well then passed through conglomerate and ended in blue clay shale. No water was struck below 40 feet and the flow ceased after a charge of nitroglycerine was fired in the well.

†**116.** Depth, 152 feet; depth of water when lowest, 130 feet, but if the well is a allowed to stand the water flows at the level of the engine-room floor, which is 10 feet below grade. The ordinary consumption is fully 10,000 gallons a day. The water can be used for all purposes. The well penetrated 140 feet of sandstone, etc., without finding enough water to keep the drill wet, but at that depth the drill became jammed in what appeared to be a crack about 2 inches wide, and an ingress of water followed the loosening of the drill. The apparent breadth of the crack may in reality be due rather to the presence of soft, decomposed rock along the joint plane than to an actual opening of the size indicated.

119. Drilled by the company in 1893, but no water was obtained except from surface seepage. It is 4,000 feet deep.

126. Depth, 572 feet. Penetrated 264 feet of quicksand and clay, the clay occurring mainly in small layers but with one 25-foot stratum above the rock.

163. Passed through 6 feet of loam, 76 feet of sand, 2 feet of gravel, and 34 feet of sandstone.

†**165** and **166.** Town water supply of Suffield, owned by Paulus Fuller. No. 165 is 230 feet deep and has a diameter of 6 inches; No. 166 is 240 feet deep and has a diameter of 8 inches. The two wells together pump at the rate of 300 gallons a minute into a standpipe containing 293,000 gallons. The water rises within about 60 feet of the surface and is rather highly mineralized. It can be used in boilers, however, but gives some scale. The wells enter rock about 10 feet below the surface.

188. Depth, 131½ feet. Passed through 70 feet of soil, consisting of light sandy soil, light gravel, coarse gravel, and hardpan, and penetrated 61½ feet of soft red

sandstone. The water naturally stands at 26 feet below the surface, and on being pumped out to a depth of 75 feet gave the following flows, as recorded by Mr. Bidwell:

Depth (feet).	Water rose (feet).	Time (hours).	Feet per hour.
75	5	¼	20
	3.5	¼	14
64	11.5	1	11.5
	18.5	2¾	6.7
52½	4.5	½	9
48	2.5	1	2.5

†**190.** Depth, 386 feet; depth of water, 326 feet; diameter, 6 inches. The pump yields 30 gallons a minute, which lowers the water 5 feet. The well passed through sand, 17 feet; clay, 56 feet; hard red gravel, 50 feet; the remainder in sandstone with the exception of two layers of "slate." Four analyses of the water have been made, according to which it ranges from moderately hard to excessively hard. It would seem that the water is free from organic impurities, but shows sulphate of lime to the extent of 590 parts to the million. It is extremely hard to the soap test. When first drawn the water is said to give off a strong odor of hydrogen sulphide.

†**191.** Depth, 113 feet; diameter, 6 inches; yield, 50 gallons a minute. Drilled in the bottom of an old open well and lies in the rock. The water is good only for drinking and garden use. It is said that when the well was first drilled the water had a very strong odor, which disappeared after the well had been used awhile. Data furnished by King & Mather.

Additional records of wells in the sandstone area of Connecticut.

[These wells were drilled by C. L. Grant, who has furnished the records. They presumably derive their water from sandstone, though a few may be in trap.]

No.[a]	Town.	Locality.	Owner.	Depth of well.	Depth to water.	Yield per minute.
				Feet.	*Feet.*	*Gallons.*
1	Berlin		New York, New Haven and Hartford R. R.	300	22	120
2	do		Berlin Brick Co	60	11	.....
3	do		do	70	8	.....
4	do		Yale Brick Co	100	19	11
5	Bloomfield		Mrs. A. S. Sage	86	18	14
6	do		M. J. Bradley	47	12	8
7	do		Grover Brown	31	17	13
8	do		Mrs. G. A. Cadwell	61	61	8
9	Farmington		Mrs. E. A. Smith	290	50	20
10	do		T. H. & L. C. Root	190	55	3
11	do		Lewis A. Storrs	208	41	25
12	do		Frank Hotchkiss	100	29	40
13	Hamden	Whitneyville	John H. Burton	50	10	15
14	do	do	W. F. Downer	67	27	7
15	do	do	Edw. Davis	56	9	10
16	do	do	Geo. W. Ives	65	13	8
17	do	do	Mr. Johnson	58	25	30
18	do	Mount Carmel	A. E. Woodruff	50	12	7
19	do	do	Chas. Wheeler	50	17	8
20	do	do	Sylvester Peck	36	21	6
21	do		Newton Archer	38	18	.....
22	do		Wm. Benham	68	28	3
23	Hartford		Hartford Woven Wire Mattress Co.	246	16	10
24	do		Retreat for Insane	180	24	20
25	do		W. C. Wade	125	11	50
*26	do		Ropkins & Co. Brewery	200	0	60
27	do		Long Bros	200	11	29
28	do		H. E. Patten	110	10	150
29	do		Hartford Light and Power Co	200	2	120
30	do		do	228	1½	150
31	do		do	201	1½	120
32	do		do	200	0	150

[a] For additional details, see page 128.

Additional records of wells in the sandstone area of Connecticut—Continued.

No.	Town.	Locality.	Owner.	Depth of well.	Depth to water.	Yield per minute.
				Feet.	*Feet.*	*Gallons.*
33	Hartford		Herold Capitol Brewing Co	300	Flows.	250
34	do		Allyn House	318	25	50
35	do		Geo. M. Brown	240	25	45
36	do		Brady Bros	159	15	15
37	do		D. F. Keenan	140	29	10
38	do		Keney Park	170	32	16
39	do		Hotoph & Carlson	155	25	12
40	do		Frank S. Tarbox	57	9	5
41	do		do	67	19	2
42	do		E. G. McCune	110	23	12
43	do		Geo. F. Hubbard	37	0	7
44	do		do	62	22	14
45	do		Thos. E. Moore	60	20	3
46	do		W. S. Mather	37	0	.....
47	do		Wm. O'Brien	50	20	11
48	do		Addison & Impey	63	27	8
49	do		Johnson & Weeks	49	20	11
50	do		Wm. Rogers	110	75	5
51	do		Peter Peterson	50	10	9
52	do		A. Hepburn	50	11	8
53	do		C. L. Bailey	48	21	11
54	do		H. G. Abbey	35	17	7
55	do		Andrew Nason	28	12	5
56	do		B. L. Chappell	50	16	12
57	do		Geo. E. Hurd	50	11	8
58	do		M. H. Erickson	37	13	10
59	do		Dr. W. Crane	60	30	2
60	do		C. A. Green	50	12	6
61	do		E. B. Jerrum	50	15	11
62	do		O. Bengston	50	10	8
63	do		F. H. Seymour	70	30	8
64	do		Geo. J. Maher	65	18	13
65	do		A. M. Weber	75	25	5
66	do		R. Balinson	53	5	9
67	Middletown		A. B. Calef	75	40	.....
68	New Britain		W. E. Bradley	40	18	.....
69	do		Dennis & Co	195	12	40
70	do		A. B. Johnson	200	38	32
71	do		do	60	7	12
72	do		J. P. Curtis	250	13	10
73	do		Wm. Derby	80	49	6
74	do		A. W. Stanley	237	18	5
75	do		Coburn Land and Lumber Co	173	1	47
76	New Haven		Geo. W. Ives & Son	50	Flows.	.....
77	do		do	200	3	10
78	do		A. B. Hendryx	254	.....	65
79	do		Lion Brewery	103	.....	60
80	do		National Wire Co	300	12	58
81	do		do	245	112	45
82	do		H. H. Olds & Co	75	35	.....
83	Newington		Center school district	67	18	20
84	do		E. E. Pimm	24	15	5
85	do		Mrs. S. F. Robbins	91	28	12
86	do		Newton Osborn	159	.....	18
87	do		J. G. Paradise	73	21	12
88	North Haven		F. L. Stiles	83	14	35
89	do		I. L. Stiles & Son	102	6	30
90	Plainville		John Coughlin	28	2	.....
91	do		N. Terrell	50	12	8
92	do		P. Horan	48	22	.....
93	Rocky Hill		J. K. Green	25	.....	4
94	Simsbury		W. L. Cushing	212	125	17
95	do	Tariffville	Connecticut Tobacco Corporation	331	36	30
96	do	do	Mrs. G. C. Willoughby	61	34	4
97	Southington		D. Green	66	24	5
98	do		Ætna Nut Co	.....	.....	.....
99	Suffield		E. A. Fuller	40	6	6
100	do		Dr. M. T. Newton	63	14	10
101	do		A. C. Harmon	45	6	3
102	do		David Guy	48	18	3
103	do		Second Baptist Church	60	13	4
104	do	West Suffield	Frank S. Root	135	9	12
105	Wallingford	Yalesville	G. I. Mix & Co	100	6	40
106	do	do	J. H. Yale	67	45	.....
107	do	do	C. W. Michaels	90	118	.....
108	do	Quinnipiac	C. T. Stevens	40	Flows.	4
109	West Hartford		Jas. Thompson	110	15	23
110	do		E. C. Wheaton	135	20	35
111	do		Mrs. Kate Gallagher	53	9	3

Additional records of wells in the sandstone area of Connecticut—Continued.

No.	Town.	Locality.	Owner.	Depth of well.	Depth to water.	Yield per minute.
				Feet.	*Feet.*	*Gallons.*
112	West Hartford		Geo. V. Brickley	30	15	12
113	do		L. N. Burt	52	13	6
*114	do		P. H. Reilly	175	15	40
115	do		D. F. Crozier	100	13	30
116	do	Elmwood	Mrs. E. W. Talcott	51	23	8
117	do	do	Jas. H. Waldron	195	39	6
118	Wethersfield		J. H. Rabbett	30	2	12
119	do		Rev. Lynch	70	30	35
120	Windsor		C. D. Reed	101	12	18
121	do	Poquonock	Connecticut Valley Tobacco Co	150	100	4

NOTES.

26. Depth, 200 feet; diameter, 6 inches; yield, 60 gallons a minute. The ordinary yield of the well is 25 gallons a minute and it flows if left standing. The water is too hard for boilers.

114. Sunk in the "Posterior" trap sheet, which at this locality is comparatively thin. The thickness of the trap has not been determined, but at least two-thirds, and possibly three-fourths, of the depth of the well must be in the "Posterior" shales which underlie the sheet, and it is very probable that the water does not come from the trap at all, but from the underlying shale.

WELLS IN TRAP.

Owing to the rugged topography of the main trap ridges few houses are built on them and consequently few wells have been drilled in rock of this character. In the vicinity of Hartford there are several wells which have been sunk directly into trap and obtain yields of 2 or 3 gallons a minute. The greater number of successful wells in rock of this type pass entirely through the trap and obtain their supplies from the underlying sandstone or shale.

All exposures of trap show an extraordinary development of jointing, and in cliffs, as at East Rock and West Rock in New Haven, the vertical joints cut the formation from top to bottom and usually show weathering, indicating the past action of water. In large trap exposures it is unusual to strike streams of water, which are so characteristic of the quarries in crystalline rocks, although it is said that in one of the Hartford quarries two days after a heavy rain water will begin to seep out of the joints at the base.

The field evidence indicates that the chances are small for obtaining water by drilling on the higher parts of the trap ridges, as the rock is so completely fractured at the surface as to allow the water to pass through and escape at lower levels, and at a short distance below the surface the joints are too tight to admit water in quantity. On such ridges, however, supplies may generally be obtained by shallow dug wells in the overlying drift.

Some interesting wells in trap have been described[a] by M. L. Fuller and W. H. C. Pynchon, as follows:

W. E. Pratt [*Rocky Hill*].—This well is located in the thin "Posterior" sheet of trap. It was drilled in the bottom of an old open well, 20 feet deep, which entered the rock for a distance of 6 feet. From this point the well was drilled 30 feet through trap, when it broke into the underlying sedimentaries, which it pierced to the depth of 1½ feet. This well therefore gives a section of 14 feet of soil, 36 feet of trap, and 1½ feet of sedimentary rock—a total depth of 51½ feet. This brings the bottom of the well about 50 feet above the surface of Connecticut River, which flows by it only a few hundred feet eastward. The diameter of the well is 6 inches and the maximum amount of water obtainable is a little less than 1 gallon a minute. The well pumps dry in thirty minutes. The water is fair for drinking, but is excessively hard.

J. K. Green [*Rocky Hill*].—Depth of well, 26 feet; depth of water, 25 feet; diameter, 6 inches; yield not given. The well is in trap rock. Data by Grant.

Hotel Russwin [*New Britain*].—The depth of the well is 152 feet, and the depth of the water at the lowest 130 feet, but if the well is allowed to stand the water flows at the level of the engine-room floor, which is 10 feet below grade. The ordinary consumption is fully 10,000 gallons a day. The water is very pure and can be used for all purposes.

[*Wells at Cedar Mountain.*]—The wells * * * at Cedar Mountain, southwest of Hartford, * * * are on the property of Dr. Gordon W. Russell, who sunk the wells largely as an experiment and who has shown much interest in scientific matters. The mountain is a part of the ridge of the "Main" trap sheet, and has a maximum elevation of about 360 feet above the sea. Its western face is very steep, dropping 250 feet to the plain within a distance of two-fifths of a mile, and is actually precipitous near the summit. The eastern face slopes more gradually, dropping about 120 feet to the valley occupied by shales, about three-fifths of a mile distant. It is in all a typical trap ridge.

Well A is an ordinary open well and was dug to supply the needs of the farmhouse. It was opened 9 or 10 feet to the rock, but the water became shallow in summer. It was then sunk 1 or 2 feet into the loose, greatly jointed surface trap and has since given an abundance of water for domestic uses. The supply, however, fluctuates regularly with the wetness or dryness of the season. From the well mouth the mountain side with its drift covering rises steadily for two-fifths of a mile to the west till it reaches the crest, which is about 100 feet above the well. The supply is clearly the surface water contained in the soil and in the heavily jointed upper surface of the trap, the source also of a little stream which lies a little farther up the ridge.

Well B is located about 200 feet south of well A. It passes through 9 feet of soil and then through about 290 feet of trap rock, at which point the string of drilling tools wedged fast, possibly along a joint plane. The well is 6 inches in diameter. On illuminating it brightly for a considerable depth by light reflected from a mirror, it appeared that no water came into it except from the shattered upper surface of the trap sheet, as in well A. The drill had not entered the underlying sediments when the well was visited in 1902, notwithstanding the fact that the bottom of the well was much below the level of the western plain.

Well C is located about three-fourths of a mile farther south and a little farther east than the other two wells. It has a depth of 103 feet. It was thought from the residue brought up by the sand bucket that the well entered the sedimentary beds below, but in view of the record of well B and the thickness of the "Main" sheet this is extremely doubtful. Water was struck at a depth of 38 feet from the surface in a joint, the yield being 32 gallons an hour. At the present depth the well is capable of giving 90 gallons an hour, the water probably coming through joints from a level below the well bottom

[a] Water-Supply Paper U. S. Geol. Survey No. 110, 1905, pp. 88, 89, 100, 101, 103.

and rising to within 25 feet of the surface. During the drilling light was reflected down the bore and water was seen coming in through the trap, and in the opinion of the driller, Mr. H. B. King, of Hartford, from the downhill side. However this may be, we have here a well near the summit of the mountain whose bottom is above the level of the lowlands on either side, with water coming in through the trap and rising to a point about 175 feet above the plain three-fourths of a mile to the west and about 70 feet above the valley one-fourth of a mile to the east. The top of the well is about 280 feet above sea level.

PRACTICAL APPLICATIONS.

YIELD OF WELLS.

The sedimentary rocks of Connecticut possess large storage capacity between strata, in joints, along faults, and within the rocks themselves, and it is but rarely that a well sunk into sandstone, conglomerate, or shale does not obtain water from one or all of these sources in sufficient amount for domestic purposes. No enormous supplies running into thousands of gallons a minute, such as are obtained elsewhere in the United States, are found, and in some parts of the State difficulty has been experienced in obtaining sufficient supplies for large manufacturing plants. Wells in sandstone offer the best chances for large supplies, shale coming second, and conglomerate third. A few wells in conglomerate at New Haven encountered dry rock from top to bottom of the drill hole. One well on George street, 500 feet deep, obtained no water after passing through the cover of glacial drift, and another well remained dry to a depth of 4,000 feet. Such wells should not be abandoned "without a thorough test of every water horizon, however small. The casing, if possible, should be raised above the level of the water-bearing bed, a pump inserted, and the supply measured. When it is impossible to remove the casing, it can be destroyed at the water horizon by a shot of nitroglycerine, which will also at the same time tend to loosen up the surrounding rock and increase the flow. Supplies have frequently been developed at horizons which were not at first thought worthy of testing and which were originally drilled through without stopping and cased off."[a] Of the 194 wells recorded on pages 116–123, only 11, or 5.6 per cent, failed to obtain 2 gallons a minute, the minimum amount desired for domestic purposes. Drillers are naturally averse to reporting well failures, yet considering the number of successful wells of which no records are available the above percentage is probably close to the facts.

The average yield of 112 wells in sandstone reported in the tables is 27½ gallons a minute, the largest being 350 gallons and the smallest two-thirds of a gallon. The 107 wells included in the supplementary list furnished by C. L. Grant (pp. 126–128) have an average yield of 26 gallons. As a rule, the well that encounters the largest number of joints and bedding planes has the largest supply of water, and there

[a] Water-Supply Paper U. S. Geol. Survey No. 110, 1905.

is, therefore, an increased yield with increased depth. This statement, however, is true only for wells less than about 300 feet in depth (see below), and many exceptions are to be noted. A well which strikes a favorable bedding plane between sandstone and shale, or drains water from a contact of trap and sandstone, or strikes a fault zone may yield large amounts at slight depths. In fact, the water moves so freely through the rock that wells sunk to lower levels or located more advantageously may drain a neighboring well, thus making it useless. (See pp. 108–109.)

The abundant and uniformly distributed rainfall of Connecticut (see p. 24) and the freedom of circulation of ground water in the Triassic sediments account for the slight variation in yield throughout the year. Few drilled wells in rock show seasonal variations. A few record a decrease in summer; in several others the supply has increased since the wells were dug. Mr. Grant is of the opinion that "in general, the wells in the Triassic area have increased their flow with age." This seems to be due to the enlargement of seams and joints caused by the washing out of the decomposed rock ("clay"). "Water from black shale," says Mr. Grant, "clears up in about two hours, but that from red shale remains cloudy for a week or two." In many wells the water has become clearer as the years have passed. The height at which water stands in the well is also remarkably uniform.

DEPTH OF WELLS.

Two geologic myths seem to have attained the dignity of facts in the popular mind; one is that ore veins increase in richness with increasing depth, the other that water is more abundant and of better quality in proportion as it comes from greater depth. So far as Connecticut's water supply is concerned, the facts are not in accord with popular opinion. Though water is drawn from sandstones at all depths between the surface and 800 feet, yet the greatest number of failures are in wells exceeding 400 feet in depth. The reason for decreased supply at greater depth is the decrease in the number of joints and the tightening of both joints and bedding planes. The average depth of 287 wells, including the three deepest, one of them 4,000 feet, is 144 feet. At $2.26 a foot, which is the average cost of 67 wells, the cost of the average well is $335.44. The depth to the principal water horizon is even less than the depth of the wells. In 63 wells with an average depth of 127 feet the principal source of water was 97 feet below the surface. The depth to the surface of the water in 144 wells in sandstone averages 23 feet. Of the 314 wells recorded in sandstone, shale, and conglomerate, 75 per cent are less than 200 feet deep, 90 per cent less than 300 feet, and only 5.6 per cent more than 400 feet; 47 per cent, including some of the best wells in the Connecticut Valley, are less than 100 feet deep.

In view of these facts and in consideration of the increased difficulty and cost of deep-well construction, it is good practice to abandon a well that has not obtained satisfactory supplies at 250 to 300 feet. Two or three wells 200 feet deep could be drilled at the cost of one 500-foot well, and the prospect of obtaining water would be greatly increased. In case a well is abandoned, the new location should be as far as possible from the old. In fractured rock favorable conditions may be found a few hundred feet distant. Wells in shale may be sunk to greater depth before abandoning the site, as is indicated by the fact that of sixteen deep wells in shale two are between 100 and 200 feet deep, five between 200 and 300 feet, four between 300 and 400 feet, two between 400 and 500 feet, and three more than 500 feet.[a]

QUALITY OF WATER.

The table of analyses shows that the composition of water in Triassic strata varies greatly, for wells only a few hundred feet apart may show marked differences in mineralization. One reason for this can be traced primarily to the inclination of the strata. As the rocks dip eastward at an angle of 15° or more, the area tributary to each well is rather small; a 500-foot well, for instance, would have a supply basin of considerably less than one-sixth of a square mile. Therefore different wells are supplied from different sets of beds, which differ from each other in their composition and consequently in their effect on the water passing through them. In general, the waters of the Triassic are so highly mineralized as to be undesirable for boilers without purification, thus strongly contrasting with those obtained from wells in crystalline rock. (See p. 168.) They are not too hard for cooling, washing, and certain other manufacturing purposes, nor for domestic use. Many wells show 500 to 2,500 parts per million of dissolved solids, including not only incrusting carbonates, but also the more undesirable sulphates. The water percolating through sandstone and shale is usually harder than that in joints and in bedding planes, and water of different quality may come from each stratum.

TEMPERATURE.

The temperature of well waters is determined by the depth from which they are drawn. At depths less than 50 feet the temperature of the water will roughly vary with the temperature of the air, which for Connecticut is 45° for the spring season, 67° in the summer, 51° in the fall, and 36° in the winter.[b] Below about 50 feet the temperature increases at the rate of 1° for each 60 feet.

[a] Water-Supply Paper U. S. Geol. Survey No. 110, 1905, p. 99.

[b] These figures are based on the mean seasonal temperatures of Storrs, New Haven, and Cream Hill, combined, for the years 1893–1903, 1873–1903, and 1897–1907, respectively, as given on pages 24, 25.

HEIGHT OF WATER IN WELLS.

Water in wells tends to reach a certain level, which remains constant with the exception of slight seasonal variations and changes produced by pumping. The height at which this water level stands depends on the character and permanency of the supply. In some wells the water stands at the rock surface, in others above or below that surface, and in a few it is under hydrostatic pressure and reaches the earth's surface as a flow. The topographic location is another factor in determining water level in wells, for, as shown in the table below, the water in valleys tends to rise above the rock floor, whereas about half of the wells on hills and slopes maintain a level within the rock. Considered as a whole, the water level in the Triassic sandstone stands 23 feet below the surface of the ground.

Height of water in wells.

Location.	Number of wells averaged.	Percentage with water level—		
		Below rock surface.	Above rock surface.	Even with rock surface.
Hills	28	46.4	50	3.6
Valleys	59	28.8	67.8	3.4
Slopes	29	48.3	44.8	6.9

FLOWING WELLS.

As stated on page 49, the primary conditions for flowing wells are (*a*) strata capable of holding large amounts of water, overlain by strata which are relatively impermeable; (*b*) outcrops of the strata where they may receive the surface water, and (*c*) a suitable dip to the rock. All these conditions are present in the Triassic areas of Connecticut. Sandstone and shale are interstratified, forming the couple which produces artesian wells in the Dakotas, New Jersey, Texas, and elsewhere. Lava flows alternate with the sandstones and shales, a condition which makes an artesian basin in parts of Idaho.[a] The edges of the water-bearing strata are well exposed, the rainfall is ample, and there is a dip to the strata of 15° or more to the southeast. Under normal conditions the Connecticut lowland would therefore form an unusually good artesian basin, and wells sunk anywhere along the western border of the Triassic area would procure large supplies, as shown in figure 19. This opportunity of obtaining artesian wells is almost entirely destroyed by two circumstances. First, the region is crossed by a series of faults and the strata are broken into huge blocks uplifted on the west side. The continuity of the water-bearing beds is therefore destroyed. But, even under these conditions, artesian

[a] Russell, I. C., Bull. U. S. Geol. Survey No. 199, 1902, pp. 178–180.

basins of moderate extent (fig. 20) would be present were it not for the fact that the strata between the fault lines are cut by joints which

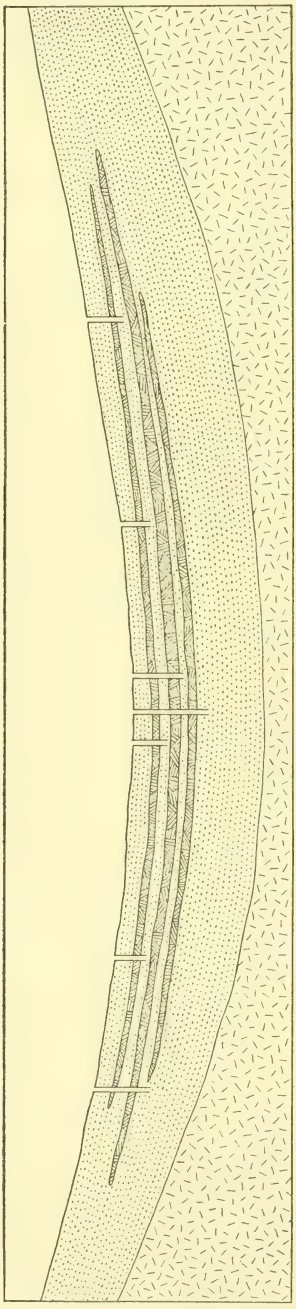


FIGURE 19.—Section of the Connecticut Triassic area as a synclinal basin—conditions favorable for artesian wells.

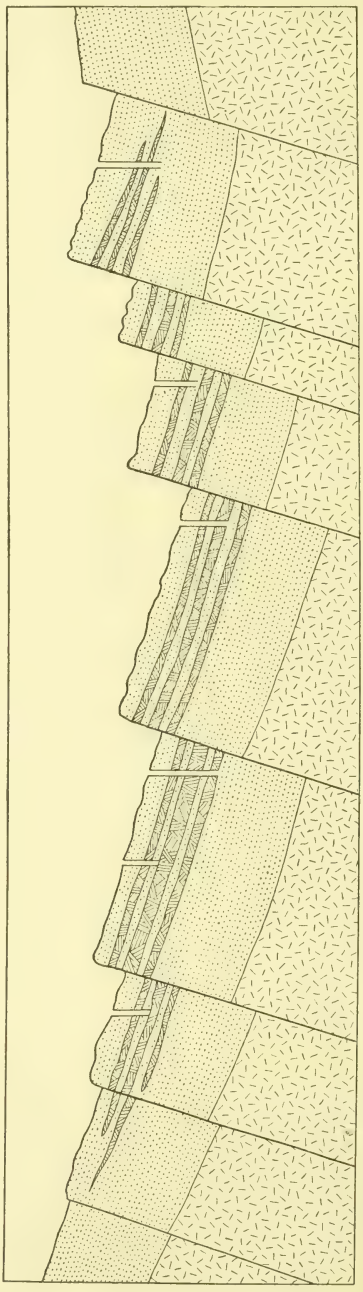


FIGURE 20.—Section of the Connecticut Triassic area as a simple faulted monocline—conditions favorable for several small artesian basins.

run in all directions and are but short distances apart, several being present in each 100 feet (fig. 21). The continuity of the beds is thus

further disturbed and the existence of unbroken beds, either as water bearers or water retainers is made impossible. All the strata, including the lavas, have taken part in this faulting and jointing, with the result that instead of numerous flowing wells throughout the region, there are a few the waters of which rise slightly above the surface. Some of the flowing wells derive their water from local bedding planes in rock; the others from the contact of rock with the cover of glacial till.

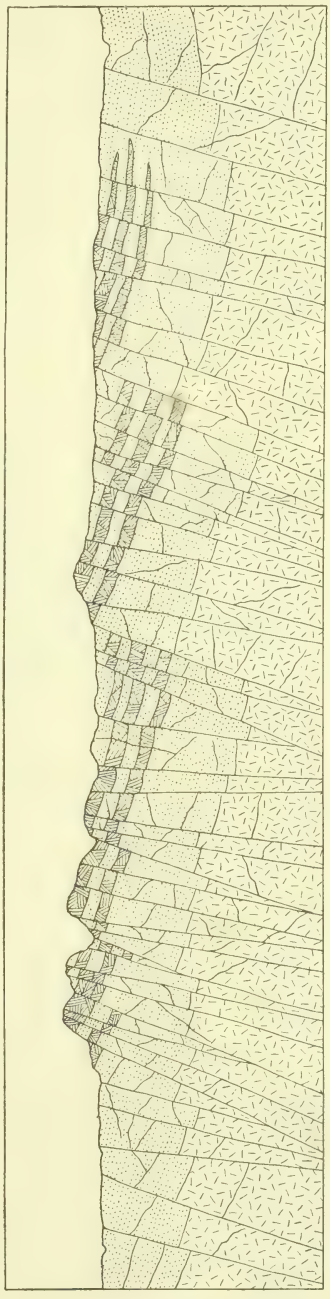


FIGURE 21.—Section showing actual condition of the Connecticut Triassic area—faulting and jointing developed to such an extent as to preclude the possibility of large artesian basins.

LOCATION OF WELLS.

Two considerations will usually control the location of wells—the amount and the quality of the water desired. To insure good quality requires a location selected with reference to freedom from contamination by drainage from barns, cesspools, houses, factories, etc. High ground with a surface cover of glacial material is a better location than bare rock. A well in low ground will usually yield more water at less expense, but the danger of contamination is greater. When it is proposed to construct a well, the condition of existing wells in that vicinity or in the same rock type should be studied with care. The direction, opening, continuity, and number of joints in the rock should be observed; also the dip or inclination of the strata and the presence of beds of shale or trap.

It is to be remembered that water in bedding planes passes up as well as down an inclined surface. The usual experience, as stated by C. L. Wright, of Augerville, is to find water at less depths on eastern slopes of hills than on western slopes, because of the eastward dip of the strata. There are numerous examples of both wells and springs,

however, which indicate that water flows up the slope after being fed into the bedding planes by joints. A well at Thompsonville, illustrating movement of this type, is described on page 124. The water in this well is 25 feet higher than the water in Connecticut River, near by, which might otherwise be its source; the water-bearing bed does not outcrop farther east; and there seems to be no source of supply other than joints or faults. A well at the "old Talcott tower," near the edge of a 700-foot cliff, is believed to derive its meager supply from water moving up the 15° slope from the east. The hundreds of springs located along the western faces of low sandstone ridges that derive their water from a combination of joints and upward-sloping bedding planes may be illustrated by a spring on the estate of A. I. Ward, at Mount Carmel. (See fig. 22.)

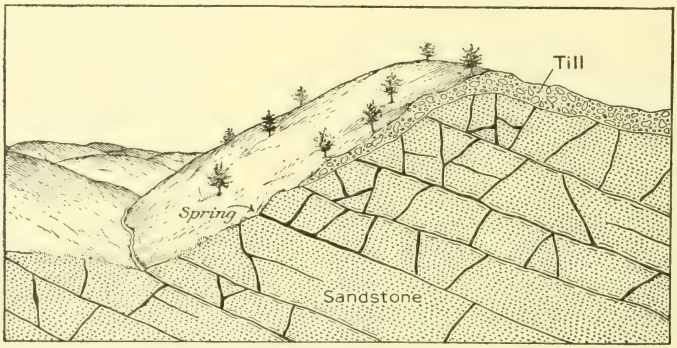


FIGURE 22.—Spring deriving its supply from joints and upward-sloping bedding planes.

STATISTICAL TABLES.

Yields of water at various depths in the rock below the covering of surface material.

"Vol." = average yield in gallons per minute; "No." = number of records from which the average is taken.]

Depth in feet.	Vol.	No.	Depth in feet.	Vol.	No.
0–30	4.7	3	110–200	27.6	53
30–50	14.8	40	200–300	56.4	41
50–70	11.1	44	300–400	40.7	7
70–90	17.7	21	400–500	185.0	6
90–110	20.3	29	500–650	40.0	5

The foregoing table requires a little explanation, especially in regard to wells more than 400 feet in depth, where the recorded yield of 185 gallons a minute does not represent a true average. This estimate is the average of the yield of five wells in Hartford and one in South Manchester, in both of which places unusual conditions prevail. Moreover, the principal source of water of these wells is at a less depth than 400 feet, so that the same yields would have been obtained if drilling had stopped at 300 to 400 feet. Considered in this light, the data from wells 400 to 500 feet in depth indicate the presence of

water in bedding planes down to 400 feet and should go to swell the average yield of wells 200 to 300 feet and 300 to 400 feet deep. The figures for wells more than 500 feet in depth likewise convey a wrong impression of the relation of yield to depth. The five wells included in the table report yields of 1, 2, 7, 75, and 125 gallons a minute. In all these wells the principal source of water is less than 300 feet and in one well less than 50 feet below the surface. When these facts are taken into account the yield of wells more than 500 feet in depth drops to an average of less than 10 gallons a minute.

Average yields of wells in various locations.

Location.	Average yield (gallons per minute).	Number of records.
Valleys	64.3	6
Hills	44.4	24
Slopes	17.7	14
Plains	42.7	46

Relation of level at which water stands in wells in various locations to surface of rock which marks bottom of overlying drift. [a]

Location.	Number.	Percentage of wells with water level below rock surface.	Percentage of wells with water level above rock surface.	Percentage of wells with water level even with rock surface.
Hills	28	46.4	50.0	3.6
Valleys	8	12.5	87.5	0.0
Slopes	29	48.3	44.8	6.9
Plains	51	31.3	64.7	4.0

[a] A summary of the results for all wells may be found on p. 133.

Average depth from surface to water level in the well.

Location.	Depth to water.	Number of records.
	Feet.	
Hills	31.9	37
Valleys	16.9	10
Slopes	21.2	26
Plains	19.9	53

Average depths, in feet, of surface material, of rock, and of the entire well for the records at hand, exclusive of wells more than 400 feet in depth and of wells known to be dry.

Location.	Average depth of surface material.	Average depth in rock.	Average total depth.	Number of records.
Valleys	82.5	199.5	282.0	6
Hills	39.4	73.9	113.3	30
Slopes	20.4	95.1	115.5	22
Plains	39.3	93.8	133.1	50

NOTE.—Average total depth of all these wells is 161 feet.

CHAPTER VI.

WATER IN THE GLACIAL DRIFT.

INTRODUCTION.

Exposed rock surfaces in Connecticut are confined largely to hill summits, cliffs, river valleys, and the shore line, and their combined area probably amounts to less than one-tenth of 1 per cent of the 4,965 square miles constituting the area of the State. Where rock outcrops are absent, glacial drift forms the surface covering. The three classes of glacial material in which ground water occurs are till, stratified drift, and clay.

CHARACTER AND WATER CAPACITY OF DRIFT.

TILL.

Till varies in texture from loosely compacted bowlders a few inches to several feet in diameter to a firm, dense, securely cemented mass of small rock fragments and clay, popularly called "hardpan." The composition of an average deposit of till is shown by the following mechanical analysis of the so-called Triassic stony loam from Bloomfield:

Mechanical analysis of stony loam from Bloomfield.[a]

	Diameter of grains.	Per cent.
	Millimeters.	
Gravel	2 –1	2
Coarse sand	1 – .5	3.35
Medium sand	.5 – .25	8.60
Fine sand	.25 – .15	31.25
Very fine sand	.1 – .05	34.22
Silt	.05 – .01	4.35
Fine silt	.01 – .005	6.20
Clay	.005– .0001	6.57
Loss at 110° C.		1.36
Loss on ignition		2.03

[a] Field Operations, Div. Soils, U. S. Dept. Agr., for 1899, p. 131.

The soil represented by the foregoing analysis is the fine earth after coarse gravel and bowlders, varying in size from an inch to 7 or 8 feet

in diameter, have been removed. The amount of gravel and undecomposed rock invariably exceeds 5 per cent, and may exceed 50 per cent.

The heterogeneous character of till makes it impossible to estimate its water-bearing capacity for any large area. The amount of clay present, the size, shape, and composition of the constituent bowlders, and the degree of compactness vary within wide limits, and therefore determinations of absorptive ratios apply only to the sample tested. Determinations of water capacity are made still more uncertain by the presence of irregular deposits of sand and gravel included within the till. The loosely compacted till has practically the capacity of conglomerate; the "hardpan" variety is almost as impervious as shale.

A mass of till collected near Yale Field, New Haven, was found after five days of continuous drying to weigh 22 pounds. After soaking in water for one day and being allowed to drain the added water had increased its weight to 24.87 pounds, a gain of 2.87 pounds, which showed an absorption percentage of 11.55, or 3.46 quarts to a cubic foot of till. This is probably not far from the average capacity of till in Connecticut.

STRATIFIED DRIFT.

Stratified drift consists of sands and gravels with local clay bands and is composed of rounded waterworn fragments of the more resistant rocks, like granite, trap, and quartzite, together with an abundance of grains of quartz, mica, garnet, magnetite, etc. It owes its origin to streams, and especially to the water produced by the final melting of the continental ice sheet. As contrasted with till, stratified drift occurs in layers of various degrees of coarseness, depending on the velocity of the stream which deposited the débris.

It must not be supposed that the stratified drift presents uniform conditions over large areas, for there are several types of the drift, each varying in texture, structure, and topographic appearance, in accordance with their method of formation. Flood-plain deposits and terraces contain numerous fine clayey layers. Delta deposits made in bodies of standing water exhibit strata of sand, gravel, and silt inclined at various angles, and the different sets of beds contain water in different amounts.[a] The grains composing sand and gravel come into contact with one another, but are so placed that there is much unoccupied space between them. Sand is practically sandstone with cementing material removed and the water capacity proportionately enlarged. As a reservoir of ground water, stratified drift is therefore very important. Such material has been found to contain an amount of water equal to over 30 per cent of its volume.

[a] Crosby, W. O., Water-Supply Paper U. S. Geol. Survey No. 145, 1905, pp. 177–178.

The proportions of different sizes of grains in the average sand of the New Haven plain, are shown by samples from four localities analyzed by Freeman Ward, as follows:

Size of grains in sand from New Haven plain.

Size of grains.	1.	2.	3.	4.
$\frac{1}{2}$ inch to $\frac{1}{4}$ inch	0.9	2.3	0.6	0.8
$\frac{1}{4}$ inch to $\frac{1}{8}$ inch	.7	2.7	1.6	1.6
$\frac{1}{8}$ inch to $\frac{1}{16}$ inch	1.1	10.0	5.5	6.3
Less than $\frac{1}{16}$ inch	97.3	85.0	92.3	91.3
	100.0	100.0	100.0	100.0

Rain water is freely imbibed by stratified drift, and accordingly the surface dries very shortly after showers, and this material furnishes little water to streams. The water, however, stands close to the surface and the sands of plains and kames are thoroughly saturated. On the North Haven sand plain there is "plenty of moisture a few inches below the surface, even in a protracted drought."[a]

CLAY.

The clays of Connecticut are largely the result of the deposition of fine material in lakes of glacial origin. They are accordingly stratified and usually contain layers of "strong clay" interbedded with sandy clay, quicksand, and sand of coarser textures. Clay consists of minute particles of kaolin, quartz, feldspar, mica, iron ores, etc., and when compacted under pressure these fragments are so nearly in contact as to give little pore space. However, the very small openings between the grains permit the access of much water, for each space acts as a capillary tube and the clay is expanded. The fine-grained clays, therefore, absorb and retain large amounts of water. That abundant water is present is indicated by the mud cracks in exposed clay surfaces and by the shrinkage which takes place on drying—an amount often over 10 per cent. The total amount of water in the brick clays of Connecticut is usually between 30 and 40 per cent. Most of the commercial clays of the State "contain enough water to make them highly plastic, so that they can be tempered without addition of more water."[b]

THE DRIFT AS A WATER RESERVOIR.

The mantle of glacial drift spread over Connecticut is perhaps the most important single factor in the ground-water supply of the State, because it contains abundant water in itself and controls the supply

[a] Britton, Bull. Torrey Bot. Club, vol. 30, 1903, pp. 571-620.

[b] Loughlin, G. F., The clays and clay industries of Connecticut: Bull. Connecticut Geol. and Nat. Hist. Survey, No. 4, 1905, p. 63.

of water to the underlying rocks. The bed rock exposed on the summits and sides of hills is not in a position to absorb water. It is apparent that the greater part of any rainfall on such surfaces would run off immediately; in fact, a locality where even 2 per cent of the precipitation was absorbed by the rock would be exceptional. Even where there are wide-open cracks on the rock surface, the greater part of the water would run off before it could be absorbed by the few joints, which, not far below the surface, are so tight as to allow very slow passage to the water.

On the other hand, where the rock is covered by glacial material the water does not run off rapidly but is absorbed by layers of porous sandy soil, from which in turn a considerable portion of the precipitation passes down into the rock fractures. Numerous shallow-dug wells indicate that the lower portion of the drift is in a saturated condition, being always ready to supply water to joints or faults or bedding planes below. The saturated belt in the surface material forms a constant reservoir, kept filled by uniform precipitation, from which water is delivered to the rocks to compensate for the amount removed by springs and wells. The sandy and gravelly portions of the drift are the most important reservoirs for supplying water to rock seams, for they carry a large quantity of water and allow ready passage; the clayey till, which may hold nearly as much water, allows very slow passage. The character of the overlying drift is, therefore, by its difference in permeability, largely determinative of the amount of water supplied to the underlying rock.

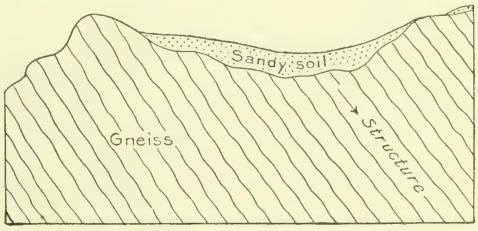


FIGURE 23.—Section of hilltop showing suitable catchment and reservoir conditions for a water supply to the rock fractures.

The condition of the rock surface is another factor in the absorption of the water. At many localities the rock is marked by minor irregularities, due to a scooping out of the rock by glacial erosion (see fig. 23), or to a dam of impervious glacial material. These small depressions in the rock serve as guiding channels to the circulation of ground water in the drift, and joints opening into these depressions have better opportunity for the collection of water than those intersecting the rock surface at intermediate and higher points. Many depressed areas which have no outlet occur in the rock. In such basins the water collects and has no escape by seepage into rock joints, and evaporation is relatively unimportant where the drift has an appreciable thickness.

Vertical joints are evidently more important than horizontal joints in giving opportunity for the entrance of subsurface water from the

drift. Owing to their parallelism to the rock surface many of the horizontal joints pitch downward when they reach the ground surface and consequently do not offer good conditions for the entrance of water, although in exposures of bare rock the fractures lying at low angles tend to absorb more of the precipitation than the vertical joints.

WATER BED AT CONTACT OF ROCK AND DRIFT.

The glacial drift rests directly upon bed rock without any intervening soil or disintegrated material. (See fig. 24.) There is a sharply drawn line of contact between the till, stratified drift, or clay and the gneiss, schist, sandstone, or other rock beneath. The contact forms a water bed, the supplies from which are larger and more permanent than those of any bedding plane in the Triassic sediments or set of joints in the crystalline rocks. As shown above, the drift is filled with water, which percolates downward more rapidly than it can be imbibed by the rocks. The result is an accumulation of water at the rock surface which brings the drift to the point of saturation. In this way the layer immediately above the rock is supplied with water to 30 to 40 per cent of its volume, an amount equal to 2.24 to 2.99 gallons a cubic foot. Wells sunk to the contact of drift and rock show a large yield. Three wells, owned by the Bradley & Hubbard Manufacturing Company, at Meriden, reach rock at depths of 203, 208, and 256 feet, and have a combined yield of 100 gallons a minute.

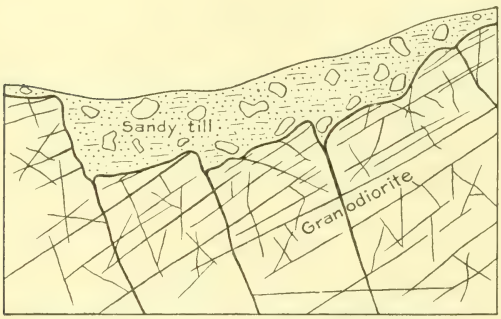


FIGURE 24.—Section showing common relation of rock surface to overlying drift.

WELLS IN TILL AND STRATIFIED DRIFT.

Probably three-fourths of all the wells in the State are shallow, open pits of large diameter, sunk in glacial material. (See fig. 25.)

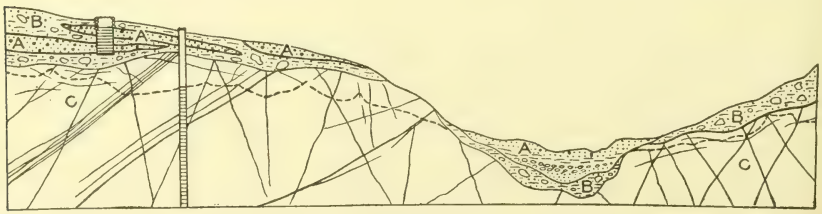


FIGURE 25.—Generalized section showing relation of rock to glacial drift. A, Layers of sand and gravel, partly saturated with water; B, bowlder clay; C, crystalline rock.

Owing to the uniform rainfall, these wells yield sufficient water for domestic purposes, but the supply is uncertain and is subject to marked seasonal and annual variation. The data collected for this report, taken in connection with investigations made by the State board of health, indicate that such wells are not to be recommended either for large yields or for unqualified purity.

WATER HORIZON.

The principal water horizons in glacial drift are the porous sandy beds confined between beds of material more or less impervious. The water-bearing layer may be sand or gravel, or even clay containing a small proportion of sand, and it may lie between layers of till and stratified drift, between different members of a stratified-drift series, or between the till and bed rock. At Stafford Springs John McCarty finds that wells in drift, which average about 20 feet in depth, are sunk through a top covering of loam, followed by 2 to 10 feet of sand and gravel, and then by a layer of hardpan 5 to 20 feet in thickness. The water comes either from the sand above the hardpan or, more commonly, from the contact between the hardpan and the underlying rock. In many places the till acts as a confining bed to retain the water stored in both sand and gravel. In fact, the hardpan variety of till exerts its chief influence as an impervious bed to limit the percolation of ground water. This relation is illustrated by the well of Mr. Coppus, at South Willington (see fig. 26), where the water enters in quantity at the junction of sand and underlying till. The most favorable water horizon, however, is in the drift, the zone lying immediately over bed rock, as explained on page 142.

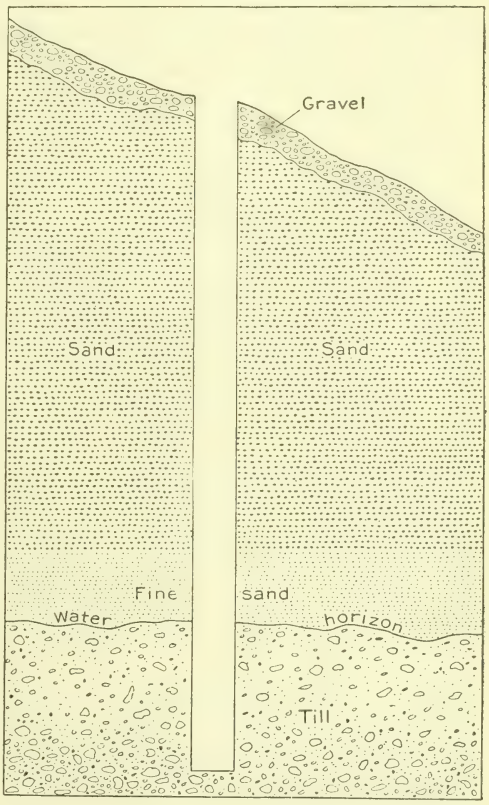


FIGURE 26.—Diagram of well at South Willington, showing water horizon at contact of till and stratified drift.

There is usually sufficient variation in the texture of the stratified drift to furnish pervious and impervious layers in contact. A slight variation in fineness of grain may be all that is necessary to concentrate the water along one plane, but the most favorable relations exist where sand overlies clay. In the brick yards at Montowese, Berlin, and North Haven water is present in quantity along the upper surface of the clay beds, and in other localities sandy layers between beds of clay furnish abundant water supplies. The whole North Haven sand plain is a good illustration of this relation. The area is underlain at a depth of 20 to 30 feet by beds of clay 5 to 20 feet thick, on top of which lie sand and gravel. Water sinks so readily into the sand that vegetation is practically absent from this area, but wells sunk to the clay bed find abundant water, and where the strata are shown in sections, as along Quinnipiac River, there is a line of springs and seepages. In certain localities the bed of clay holds the water under hydrostatic pressure, and when this cover is pierced by a well the water rises nearly or quite to the surface.

Wells sunk in till which does not contain sandy layers have no definite water horizon. In such wells the water is seen to form as a film and to drip from the surface, or to ooze out in small amounts around some of the larger bowlders. The circulation of water in such material is much retarded, and the wells are accordingly likely to vary much in yield.

DEPTH AND YIELD.

The average depth of the recorded wells in till is 24 feet, which is probably 5 feet too much, as an average for the State, because of the omission of a large proportion of shallow dug wells. The greatest depth reported is 151 feet and the least 7 feet. A few wells located at the contact of drift and bed rock flow at the surface.

The average depth of 83 wells in stratified drift is 48.3 feet, a figure probably 10 feet in excess of an average made by including several thousand shallower wells sunk in this material. The deepest well in drift is 110 feet deep and the least depth recorded is 7 feet, but the tables do not include numerous wells with depths of less than 10 feet that are known to exist.

These wells, both in till and stratified drift, probably procure all the water necessary for domestic purposes, for which they are largely used; by sinking to greater depths they could obtain much larger supplies. The average thickness of the drift cover over the sandstones is 38.4 feet and over the crystalline rocks 36 feet, an average of about 37 feet for the State. It is readily seen that the wells in till, with an average depth of 24 feet, do not penetrate to great depths in this glacial material. The wells in stratified drift are sunk deeper and take more advantage of the opportunity offered to procure large supplies from a considerable thickness of drift. In case more

water is desired, it is advisable to sink a well in drift to bed rock or a few feet into the fractured upper surface of the rock itself. These are the conditions, as explained above (p. 142) under which the largest yield of water may be obtained with a minimum depth of well.

The number of wells recorded of various depths in the till and stratified drift is shown in the subjoined statement.

Depths of wells in till and stratified drift.

Depth, in feet.	Number of wells.		Depth, in feet.	Number of wells.	
	Till.	Stratified drift.		Till.	Stratified drift.
0–30	84	31	70–90	1	7
30–50	8	21	90–110		6
50–70	1	9	110–200	2	5

QUALITY OF WATER.

Till and stratified drift, alike, are composed of fragments of all sorts of rock, and it is therefore to be expected that the quality of the water should vary within wide limits, with reference to both depth and location, and that water from different depths and from different locations should be unlike in character. The waters of wells in till derived from sandstone and limestone are sure to contain compounds of calcium, magnesium, etc., making them hard, while wells sunk in drift composed of fragments of crystalline rocks are much more likely to yield soft water. Wells in till are more liable to have hard water than those in stratified drift, because the water circulates slowly and with difficulty in material of this sort and, accordingly, has an opportunity to take larger amounts of mineral matter into solution. The tables of wells in till show 45 yielding hard water, 38 soft, and 11 medium in a total of 94 wells. In stratified drift 25 wells are reported to yield hard water, 30 soft, and 4 medium out of a total of 59.

Most wells in drift, especially if they are shallow and open and of large diameter, contain impurities. Wells of this character, especially if they have been dug a number of years and are located near buildings, are so liable to contamination that an examination of the water should be made at short intervals. In thickly settled districts the water in shallow wells is often dangerous. Many wells near the beach sunk in stratified drift give brackish water, although a number of instances to the contrary may be cited. Wells in till are much less liable to contamination by salt water, and a number of such wells are located along the shore in close proximity to the Sound. Two wells at Saybrook Point are reported to contain fresh water except during dry seasons, when the water becomes low and brackish.

WATER LEVEL.

The wells in till have an average depth of 24 feet and those in stratified drift 48.3 feet so far as recorded. The average depth to water in these wells, however, is 10 feet for the till and 20.6 feet for the stratified drift. If the thousands of unrecorded wells in the State were added to the list the average distance of water from the surface would probably be still less. These figures indicate the freedom of circulation of water, especially in the stratified drift, for the principal water horizon is at a depth of 35.5 feet and the average rise of water in the well is therefore 15 feet. Unlike the wells in sandstone and crystalline rocks, the wells in till and stratified drift are subject to great variation of water level, both annual and seasonal, and sometimes daily.

The average variation of water level of wells in till recorded on pages 148–150 is 12 feet, sufficient to render many shallow wells valueless in dry seasons. Most of these wells have a regular annual period of maximum supply in late winter or spring, when they are full or overflowing. Single showers often raise the water level because of the added supply, but much more because of pressure on the air contained in the soil. Sudden rises of water in wells amounting to several feet are frequently reported, under circumstances where the rainfall could not have had time to enter the well through the drift and where the pressure of soil air was amply sufficient to account for the phenomenon. However, it is usually impossible to tell in any particular case, how much of the rise is due to infiltration and how much to the pressure applied to the air occupying the space between the grains. The wells of Sperry & Barnes, at New Haven, fluctuate in harmony with the level of water in the Sound, rising sometimes 10 inches in advance of the tide. The change in level is probably not due to the forcing of salt water toward the well, but rather to a squeezing of the fresh water from the pores of the sand, owing to the weight of the tons of water piled up on the shore.

In stratified drift the fluctuation of the water level is not so marked, owing doubtless to the greater ease of circulation in the loose-textured sands and gravels. Sudden rises, however, due to air pressure, as explained above, are reported.

The relation of rainfall to the fluctuation of water level in stratified drift is well shown by experiments conducted at the Yale Medical School, New Haven.[a] The well in which measurements were taken is sunk in sand at 146 York street, and the rain gage was located on the roof of the Medical School building on the adjacent lot, and read on the 15th of each month. As shown by the table below, the greatest depth of water at any time was 7.15 feet and the least 5.50 feet, showing a variation during the year of 1.65 feet.

[a] Report Connecticut State Board of Health for 1889-90, p. 282.

Rainfall and variations in ground water at New Haven, 1889–90.

Month.	Rainfall.	Depth from surface to water.	Depth of water.
	Inches.	*Feet.*	*Feet.*
November	5.16		
December	6.54	21.70	7.15
January	.87	22	6.85
February	3.96	22.35	6.50
March	2.87	21.90	6.95
April	7.13	21.70	7.15
May	3.64	21.90	6.95
June	4.36	21.85	7
July	2.50	22.70	6.15
August	5.23	23	5.85
September	4.21	23.35	5.50
October	6.21	23.40	5.45
November	5.16	23	5.85
	57.84		

COST OF WELLS.

Of 82 wells in stratified drift 28 are drilled, 22 are driven, and 32 are dug. The average cost of 6-inch drilled wells is about $3.50 a foot; of 1½-inch driven wells, 70 cents a foot; and of 3-foot dug wells, $3.15 a foot.

Wells in till have an average inside diameter of 3 feet and an outside diameter of 6 feet. They are usually lined with field stone and cost an average of $3.10 a foot.

RECORDS OF WELLS IN TILL.

The following table comprises the available records of Connecticut wells in till.

Records of wells in till in Connecticut.[a]

No.	Town.	Locality.	Owner.	Diameter.	Depth.	Depth to water level.	Quality.	Use.	Cost.	Remarks.
				Feet.	*Feet.*	*Feet.*				
*1	Andover		E. D. White	7½	17	1–4		Domestic	$100	
2	do		W. Kingsbury		24	Var.	Hard	do		
3	do	Andover	—— Town	3	22	12	do	General	150	
*4	Ashford	North Ashford	George A. Keach	8	7	2	Soft	Domestic		
*5	Barkhamsted	Barkhamsted	W. F. Beach	3	16	Var.	do	Stock		
*6	Bethlehem		G. C. Stone	5	12	6+	do			
7	do		A. T. Minor	6	23		do			
8	do		F. H. Thompson	8	27	3–20	do	Domestic, stock	50	
9	Bolton		C. F. Summer		23	6+	Hard		35	
*10	do		M. W. Sperry	3½	27	10+	do	Domestic		
11	do	Bolton Center	C. M. Perry	6	18	5–10	do	do	45	
12	Canaan	Falls Village	Henry Brinton	4	16	2–8	do	do		
13	do	do	Walter Kellogg	Top, 4; bottom, 8.	22	5–16	do	do		
14	do	do	H. B. Smith	3½	18	14	do			
15	do		J. N. Van Deusen	3	16	4–10	do	Domestic	25	
16	Canton	Collinsville	S. Gibson	3	24	14		do		
17	do	do	Miss E. White	2	30		Hard	do		
18	Chaplin		C. E. Chester	3½	35	30	Soft	do		
19	Eastford	Phœnixville	M. F. Latham		30		do	do		
20	Franklin	North Franklin	A. R. Race	3½	11	7	do	do		
*21	do	do	do	10	14		do	do	53	
22	Chatham	East Hampton	H. G. Clark	4	8	5	do	do	25	
23	do	do	H. D. Chapman	3	15	Var.	do	do	75	
24	do	do	L. S. Carpenter	4	15	5	do	do	25	
25	do	do	T. S. Brown	6	22	10–16	Hard	do	40	
26	do	do	S. D. Barton	3	16	5–12	Medium	do	35	
*27	do	do	L. H. Goff	3	25	6–24	do	do	30	
28	Columbia		E. D. Dewey	Top, 2½; bottom, 4.	35	5+	do	do		
*29	do		S. D. West	4	13	3–8	Hard, iron	Domestic, stock		
30	do		H. C. Isham	3	27	12	Hard		30	
31	Eastford	Phœnixville	G. R. Dickey	3	20	4–16	do			Stoned down 3 feet.
32	Fairfield		B. F. Pease	4	12	5	Soft	Domestic		150 gallons a day; easily lowered.
*33	Goshen	West Goshen	W. H. Wadhams	2½	18	2–14	Hard	do		
34	do	do	H. G. Wright	4	15	Var.	Soft	do		
35	do		E. Carlisle	3	15		do	do		
36	do		Lyman Hall	10	20	3–13	Hard	do	75	Stoned throughout.
37	Greenwich		L. M. Close	5	18	10	do	Stock		Water comes from clay.
38	do	Stanwich	S. R. Close	4	24	Var.	Soft	Domestic		Temperature 54° F.

*39	Groton	Mystic	S. G. Fish	Outside, 8; inside covering, 3.	16	3-13	Hard	do	50	
40	do	do	C. R. Heath	2½	20	3-17	do	Domestic, stock	50	
41	Haddam		E. P. Arnold	9	8	0	do	Domestic	150	Never dry.
42	do		B. W. Kelsey		14	0	Soft	do		
43	do		E. E. Lewis	3	15	6	Hard	do		
44	Hebron	Gilead	Frederick Prentice	3	20	10-19	Soft	do		Rises in springs and lowers gradually till winter.
45	do	Hebron	F. W. Little	4	35	20		do		Rock at bottom.
46	do	Turnerville	Ben Jones	4	25	10; var.	Soft	do		Water from clay.
47	do	do	R. D. Stephens		18		do	do		
48	do	do	Edw. T. Smith	4	28	15-20	do	do		
49	do	do	Joel Jones	5	15	12	do	do		Rock at 14 feet.
50	Huntington	Shelton	A. E. Hewitt		67½	60	do	do		Water from hardpan.
51	do	do	O. J. Beard	2½	25	0-19	Hard	do		Do.
52	Lebanon		D. Blanchard	3	14	9-14	Soft			Rock at bottom; dry in summer.
53	do	Lebanon	C. H. Loomis	3	20	12	do	Domestic		
54	do	do	J. H. King	2½	19	5	Hard	do		
*55	do	do	R. E. Turner	6	28	3	Soft	do	200	
56	Litchfield	Prospect	H. S. Clark	3	17	10+	Hard	do	35	Water comes from hardpan.
57	do	do	H. N. Payne		22	8	do	do		
58	do	do	L. G. Clark	6	24	6	do	do		Do.
59	Madison		M. T. Bushnell	3	23	Var.	Soft	do		
60	do		J. Q. Buell	3	19	16	do	do		
61	do		P. P. Coe		27	5	do	do		
62	do		C. W. Scranton	3	15	3-11	Hard	Domestic, stock, irrigation.	50	Cased by tiling.
*63	do	East River	S. H. Chittenden	3	25	12-22	do	Domestic		
64	Milford		D. L. Clark	3	21	8-13	do	do	63	
65	do		E. L. Ford	3	27		Medium	do	50	
66	Montville		D. A. Botham	3½	30	10-20	Soft	do		
67	New Haven	New Haven	E. C. Hildebrand	3	14	10	do	do		
68	Newtown		L. C. Morris	3	38	10+	Hard	do	200	
69	do		Chas. Morris	3	19	4-19	do	do		Dry in summer; temperature, 46° F.
70	North Canaan	East Canaan	G. O. Dunning	2½	8	3	Medium	do	15	
71	North Branford		A. H. Hill	(b)	75	20	do	Stock	150	
72	North Stonington	Pendleton Hill	H. V. Baker	5	30	2-15	Soft	Domestic	50	Water comes from clay.
73	do	North Stonington	O. Chapman		17	5-15	do	do	43	
74	Norwalk	Silver Mine	C. N. Adams	6	14	6	Hard	Greenhouse		Yields 1,500 gallons daily.
75	Old Mystic	Old Mystic	S. H. Babcock	(b)	36			Domestic		
76	Plymouth	Pequabuck	Scott & Co	3	25	12	Hard	Drinking		From clay; temperature, 50° F.
77	Redding	Redding Ridge	D. S. Sanford	3	20	8	do	Domestic		
78	do	do	J. B. Cornwall	4	16	8	Soft	do		From clay; water is siphoned for use.
79	Sharon	Sharon	Mrs. C. Schwab	(b)	150	40	Hard	Domestic, farm	450	
80	do	do	Mrs. E. C. Schwab	(b)	152	48	do	do	456	
81	Stratford		C. H. Welles	3	32	7-20	do	Domestic		
82	Watertown	Oakville	W. H. Smith	6	14	7	do	do	75	
83	Washington	Washington Depot	E. C. Whitehead	3	18	4-10	do			

[a] Additional details concerning wells marked with an * are given on p. 151.

[b] Drilled; 6 inches in diameter.

Records of wells in till in Connecticut—Continued.

No.	Town.	Locality.	Owner.	Diameter.	Depth.	Depth to water level.	Quality.	Use.	Cost.	Remarks.
				Feet.	*Feet.*	*Feet.*				
84	Washington	Washington Depot	R. W. Squires		22	21	Hard	Domestic		
85	Westbrook	Westbrook	A. L. Burdick	3	18	7	do	do		
86	Wilton	Wilton	E. Benedict	3	20	Var.	do	do		
87	do	do	H. Chichester	4	25	7; var.	Soft	do		
88	do	do	S. Comstock	3	20	10	do	do		
89	do	do	J. Gilbert	3	21	4–19	Hard	do		
90	do	do	C. W. Horton	10	17	6–8	Soft	do		
91	do	do	W. T. Jelliffe	3½	20	14	Hard	do		
92	do	do	B. N. McQueen	3	32	10–20	Hard, iron	do		
93	do	do	J. F. Knapp	6	12	3	Soft	Stock	$96	Stoned.
94	Woodbridge		Mrs. F. P. Gilbert	3	40		Hard	Domestic		Rock at bottom.
95	do		F. I. Baldwin	4	30	2	do	Domestic, stock		Water comes from hardpan.
96	Woodbury	Hotchkissville	N. H. Bloss	4	12	6; var.	Soft	Domestic		Main supply at 25 feet.

NOTES.

1. Passes through 3 feet of moist clay loam above 14 feet of hardpan. This is one of six dug wells varying from 16 to 28 feet in depth, and is stoned, jug shape.

4. An excavated spring, the water being transported by a pipe with a 50-foot fall.

5. Passed through hardpan for the entire depth. The water level varies greatly, the well being nearly dry in some seasons. A stream the size of a lead pencil was struck 6 feet from the top and another stream was encountered below a flat rock.

6. In hardpan, with loam above. Water flows into the well from the northwest.

10. Supply said to be practically unlimited and lowered with difficulty. Well is in sandy clay underlain by hardpan.

21. Put down in 1900 through 14 feet of hardpan and obtained a strong flow from quicksand.

27. Passed through 3 feet of soil and 22 feet of "clay hardpan" containing "stones as large as a water pail." No streams of water were encountered, the water oozing from the hardpan in drops.

29. Blasted into rock 5 feet and occasionally becomes dry; 35 feet away is an unfailing well sunk 7 feet in till and containing soft water.

33. Never failing, but varies in amount of water with seasonal changes. Passes through 3 feet of loam and 15 feet of hardpan.

39. Passed through 2 feet of topsoil, 8 feet of clay subsoil or hardpan, and 6 feet of sand and gravel. Water came in from several small veins (probably from sand and gravel). Water level lowers in dry seasons, but ordinarily rises within 8 feet of surface.

43. Flows in wet seasons and occasionally runs dry at the same time as an adjacent stream. The well is located on a sandy knoll, and may be in stratified drift.

55. First 5 feet were soil and clay subsoil; first water struck at 9 feet, yielding 40 barrels a day. Remaining 19 feet through hardpan containing and underlain by coarse gravel at the bottom, from which issued a large stream of water rising within 3 feet of the surface. According to Rev. R. E. Turner, local artesian conditions prevail.

63. Struck water at 13 feet below the surface, where rocks occurred in sand and water came in as a strong flow. Has never been dry.

RECORDS OF WELLS IN STRATIFIED DRIFT.

The available records of wells in stratified drift are summarized in the following table:

Records of wells in stratified drift in Connecticut.[a]

No.	Town.	Locality.	Owner.	Type.	Topographic position.	Diameter.	Depth.	Depth to principal source.	Depth to water level.	Yield per minute.	Quality.	Cost.	Use.	Material yielding water.	Remarks.
						In.	*Feet.*	*Feet.*	*Feet.*	*Galls.*					
1	Andover	Andover	Thos. Sullivan	Drilled	Valley	5	63	50	45	.....	Soft	$300	Domestic	Gravel	Supply constant.
2	Ansonia	Ansonia	Y. M. C. A	Dug	.....	30	6	.....	1	24	...do	.....	House, boilers, plunge.	.....	
3	.....do	.....do	H. J. Smith	...do	Valley	30	84	.....	2	.....	...do	250	Domestic	.....	Water rises in well with rise of river.
4	Avon	Avon	J. P. Neville	Driven	.....	2	26	.....	14	Good.	...do	.....	...do	.....	
5	Beacon Falls	.....	C. H. Hoffman	Dug	Stream bed.	36	10	8	5	[b] 500	Hard	25	...do	Gravel	Varies with season.
6	Berlin	Berlin	E. J. Clark	...do	.....	36	16	11	11	Large.	...do	.....	...do	.....	
7	.....do	.....do	C. W. Hollister	...do	.....	36	35	4	.....	.....	...do	.....	...do	.....	
8	Branford	Branford	Richard Bradley	...do	Hill	.....	44	39–44	.....	Good.	...do	250	Domestic, stock.	Gravel, quicksand.	
*9	.....do	.....do	J. W. Nichols	...do	Slope	36	17	15	.....	Good.	...do	100	Domestic, lawn.	Gravel	
10	Brooklyn	Wauregan	Church of the Sacred Heart.	Driven	...do	6	48	48	12	Good.	Soft	150	Domestic, boiler.	...do	
11	Canaan	South Canaan	Mrs. J. B. Copon	Dug	.....	.....	17	17	2	Good.	Hard	.....	Domestic	Quicksand.	Water comes in just above rock.
12	.....do	Falls Village	R. Pendleton	...do	.....	30	12	.....	Varies.	.....	Soft	25	...do	Gravel	
13	Coventry	South Coventry.	Mrs. M. Colburn	Drilled	Slope	6	45	35	24	Small.	...do	132	...do	Clay	Water becomes soily when heavily pumped.
14	Cromwell	Cromwell	E. S. Coe	Dug	Hill	.....	40	30	.....	.....	Medium	.....	...do	.....	
15	.....do	.....do	F. K. Hallock	Driven	Slope	6	84	.....	24	.....	Hard	.....	...do	Sand	
16	Derby	Derby	Derby and Ansonia Brewing Co.	Drilled	Ridge	6	155	28	.....	50	.....	800	Brewing	Gravel	Well penetrates rock, but water comes from gravel.
17	Eastford	Phoenixville	L. N. Snow	Dug	...do	30	30	.....	.....	.....	Hard	.....	Domestic	...do	
18	.....do	.....do	M. L. Latham	...do	.....	48	28	.....	22	.....	Soft	60	...do	.....	
19	East Haddam	East Haddam	F. L. Ray	...do	Hill	36	22	.....	.....	.....	...do	.....	...do	Clay	Temperature 50° in summer, 48° in winter.
*20	East Hartford	.....	F. A. King	Driven	Plain	1¼	20	20	.....	8	Medium	.....	Domestic, stock.	Sand	Temperature 50°.
*21	East Lyme	Crescent Beach	A. P. Carroll	...do	Plain near coast.	2	16	.....	2	[c] 15	.....	[d] 3	Cottages	Gravel	Water enters at contact with rock.
22	Fairfield	Greenfield Hill	S. J. Gorman	Dug	Hill	36	48	.....	0 in winter.	[e] 2,500	Medium	.....	General	...do	Pumping lowers.

23	.....do.....	.....	G. H. Bradley...	...do.....	.....	40	27	18	8	.....	Soft.....	.....	Domestic..	.....		
24	Farmington...	Farmington...	Wm. Potts.....	Drilled...	.....	.....	78	.....	.....	.....	.....	.....	.....	Clay, gravel.	Well was blocked by clay.	
25	Glastonbury...	Buckingham..	O. E. Bailey.....	Dug.....	.....	48	24	24	.....	.....	Soft.....	.....	Domestic..	.....	Dry in dry weather.	
26	.....do.....	.....do.....	E. C. Weir.....	...do.....	Hill.....	36	16	8	Varies.	1½	...do.....	.....	...do.....	Gravel..	Water obtained by siphon.	
27	Griswold.....	Glasgo.....	Glasgo Yarn Mills.	Drilled...	...do.....	6	93	.....	26	8	...do.....	276	.....	...do.....		
28	Guilford.....	Guilford.....	C. Griswold.....	Driven...	.....	2	65	.....	.....	Good.	Hard.....	.....	.....	...do.....		
29	Haddam.....	Haddam.....	G. Parmelee.....	Dug.....	.....	40	50	46	46	Good.	Soft.....	200	Domestic..	Sand....		
30	.....do.....	.....	County Orphans Home.	...do.....	.....	.....	21	.....	.....	.....	...do.....	200	...do.....	Gravel..		
31	Hamden.....	Mount Carmel.	A. E. Woodruff.	Drilled...	.....	6	50	.....	.....	.....	.....	100	General....	...do.....		
32	.....do.....	.....do.....	Mount Carmel Bolt Co.	Dug.....	Slope.....	30	35	.....	.....	.....	Medium.....	.....	Boiler, drinking.	.....	Temperature 51°.	
33	Killingly.....	Danielsonville.	Jas. M. Paine....	Drilled...	...do.....	6	142	118	62	7	Soft.....	417	Tenements, stores.	Sand....	Water from sand at top of rock. Pumping lowers to 50 feet.	
34	.....do.....	Attawaugan...	Attawaugan Co..	Driven...	Plain.....	6	112	80	25	.....	Hard.....	375	Domestic..	Sand, gravel.		
35	Ledyard.....	Gales Ferry...	J. C. Hazler.....	Drilled...	.....	6	33	.....	15	1	Soft.....	.....	.....	.....	Easily lowered.	
36	Mansfield.....	Mansfield Depot.	A. K. Brown.....	...do.....	Valley.....	6	75	65	40	Small.	Soft, iron	300	Domestic..	Sand....		
37	Meriden.....	Meriden.....	C. Rogers & Bros.	...do.....	.....	1½	47	.....	.....	.....	Hard.....	.....	General, except for boilers.	Gravel..		
38	Milford.....	Woodmont....	A. G. Chapin....	Driven...	Slope.....	6	35	.....	.....	Good.	Soft.....	175	Domestic..	...do....		
39	.....do.....	Milford.....	B.B.B.Gregory.	Drilled...	.....	6	35	29	28	.....	Hard.....	.....	...do.....	Sand, gravel.		
40	.....do.....	.....do.....	Mrs. A. M. Coupland.	...do.....	Plain.....	6	92	25,60	.....	.....	Medium.....	.....	...do.....	Gravel..		
41	Montville.....	Uncasville.....	J. B. Lathrop....	...do.....	Valley.....	6	70	.....	55	Large.	Soft.....	210	Domestic..	...do....	Pumping does not lower.	
42	.....do.....	.....do.....	Chas. Ramage...	...do.....	...do.....	6	40	39	20	3	.....	.....	.....	.....		
43	.....do.....	.....do.....	M. E. Fox.....	...do.....	Slope.....	6	32	28	24	.....	Hard.....	.....	Domestic..	Sand....	9 feet of water ordinarily; 3 feet in dry times.	
44	.....do.....	.....do.....	J. F. Schofield..	...do.....	Plain.....	6	78	51	.....	Good.	Soft.....	234	Domestic, lawns.	Sand, gravel.	Temperature 48°.	
45	New Haven...	New Haven...	F. B. Shuster Co.	Driven...	.....	2	58	.....	20	.....	Hard.....	.....	Washing..	Gravel..	See analysis, p. 178.	
46	.....do.....	.....do.....	.....do.....	...do.....	.....	2	72	.....	20	.....	...do.....	.....	...do.....	...do....		
*47	.....do.....	.....do.....	Dining hall, Yale University.	Driven, 9 wells.	Flat.....	1,2	±27	25–27	21	.....	...do.....	.....	Condensing ammonia.	Sand....	Temperature 48°.	
48	.....do.....	.....do.....	Hygienic Ice Co..	Driven, 40 wells.	Plain.....	2	35–70	.....	*f* 20–25	160	...do.....	.....	Cooling.....	...do....	In different parts of city; temperature 52½°.	
*49	.....do.....	.....do.....	Yale University gymnasium.	Driven, 34 wells.	...do.....	1½	27	20	.....	150	...do.....	600	Swimming pool.	...do....	Temperature 52°.	
*50	.....do.....	.....do.....	Sperry & Barnes.	Driven, 40 wells.	...do.....	2	42	..	....	.....	Large.	.....	.....	General...	Gravel..	Temperature 53°. See analysis, p. 178.

a Additional details concerning wells marked with an asterisk are given on p. 156. *b* Daily. *c* 10,000 gallons daily. *d* Per foot. *e* Weekly. *f* Seasonal variation.

Records of wells in stratified drift in Connecticut—Continued.

No.	Town.	Locality.	Owner.	Type.	Topographic position.	Diameter.	Depth.	Depth to principal source.	Depth to water level.	Yield per minute.	Quality.	Cost.	Use.	Material yielding water.	Remarks.
						In.	*Feet.*	*Feet.*	*Feet.*	*Galls.*					
51	New Milford	Boardman	A. G. Barnes	Driven	Valley	2	70	.....	12	Large.	.....	.....	Domestic, stock.	General	From gravel under sand.
52	....do	....do	....do	...do	...do	2	80	.....	12	Large.	.....	.....	...do	...do	
53	Newton	Newton	C. L. Mitchell	Dug	Plain	36	22	.....	10–20	.....	Soft, iron	.....	Domestic	...do	
54	North Canaan	.....	J. D. Clemens	Driven	.....	1¼	20	.....	10	.....	Hard	*a* $3	...do	Sand, gravel.	
55	North Haven	Hamden	Jas. H. Webb	Drilled	Plain	8	143	.....	40	.....	...do	.....	Washing, stock.	Gravel	Rock below 40 feet; temperature 48°.
56	Norwalk	Norwalk	R. & G. Corset Co	Dug	Valley	36	20	.....	8	.....	...do	.....	.....	...do	See analysis, p. 178.
57	....do	.....	Roton Point Improvement Co.	...do	.....	144	10	.....	.....	.....	.....	.....	Hotel	...do	
58	Norwich	Norwichtown	Miss M. A. Cryer	Drilled	Plain	6	50	.....	.....	.....	Hard, iron.	200	Domestic	.....	Clay above gravel.
59	Old Mystic	Old Mystic	A. A. Haley	...do	Valley	6	31	.....	7	20	Soft	.....	.....	Coarse gravel.	
60	Old Saybrook	Saybrook Point.	C. E. Jackson	Dug	Plain	36	17	.....	6	Large.	Hard	25	Domestic	Sandy soil.	
61	....do	....do	J. T. Beckwith	...do	Elevation	.....	25	.....	20	.....	Medium.	50	Domestic, hotel.	Gravel	
62	....do	....do	W. G. Bulkeley	...do	.....	30	20	.....	12	.....	.....	.....	Domestic	.....	
63	Plainfield	Moosup	Floyd Cranska	Drilled	Valley	6	100	.....	10	30	Hard	.....	...do	...do	Rock at 60 feet.
*64	....do	Central Village	F. A. Carey	...do	Hill	6	55	.....	25	3	Soft, iron	.....	...do	Clay, gravel.	
65	Pomfret	Pomfret	R. J. Sabin	Dug	Slope	72	12	12	Var.	.....	Iron	25	Stock	Gravel	
*66	Ridgefield	Ridgefield	Ridgefield Water Supply Co.	Drilled, 5 wells.	Plain	6	60	.....	50	½	Soft	.....	Town supply.	...do	
67	Seymour	Seymour	Joseph Riegal	Drilled	...do	6	110	83	23	.....	...do	440	Hotel, tenements.	...do	Pumping does not lower.
68	Sprague	Baltic	Baltic Mills Co	...do	Slope	6	101	60	40	Good.	Hard	200	Domestic	...do	
69	Stafford	Staffford Springs.	A. Howard	Driven	Island	.....	35	35	.....	Good.	.....	.....	.....	...do	
*70	Union	.....	J. M. Leach	...do	...do	1½	33	.....	.....	Large.	Medium.	25	Domestic	...do	
*71	....do	Mashapaug	J. H. Howard	...do	.....	2	38	.....	20	.....	Soft, iron	.....	...do	...do	
72	....do	....do	....do	.....	.....	2	47	.....	20	.....	...do	.....	...do	...do	Temperature 52–60°.
*73	....do	....do	G. W. Crawford	Dug	.....	36	15	.....	9	Good.	Soft	.....	...do	.....	Well 8 feet away with hard water.
74	Washington	New Preston	N. B. Mead	Drilled	.....	6	110	.....	30	Small.	Milky	.....	...do	Sand, gravel.	Pumps dry.
75	Waterbury	Hopeville	Mrs. F. B. Wood	Dug and drilled.	.....	.....	53	43	42	.....	Hard	.....	...do	Gravel	

*76	.....do.....	Waterbury....	C. Tracy.....	Drilled...	Hill.....	6	200	.....	40	60	Soft.....	1,200	...do.....	...do.....	Pumping lowers 10 feet.
77	Westbrook....	Westbrook....	H. R. Parker....	Driven...	Plain.....	1¼	20	.....	12	Large.	.....	.....	...do.....	Gravel. sand.	
78	West Hartford.	Elmwood.....	Mrs. E. W. Talcott.	Drilled...	.....	6	51	.....	20	1½	Hard....	.....	...do.....	Gravel..	Pumping lowers 2 feet.
79	Westport.....	Westport.....	Westport Water Co.	Dug.....	.....	180	15	.....	.....	(b)	...do.....	.....	Town supply.	.....	
80	Willington....	South Willington.	A. Korper.....	...do.....	.....	48	28	26	21	.....	...do.....	100	Domestic..	.....	
*81	Woodbury....	Woodbury....	M. A. Hurd.....	...do.....	Valley....	36	20	.....	13	.....	Soft.....	.....	...do.....	.....	Well bottom at river level.
*82	.....do.....	.....do.....	L. J. Allen.....	...do.....	...do.....	24	31	.....	.....	.....	Hard....	.....	...do.....	.....	

a Per foot.

b 150,000 gallons daily.

NOTES.

9. Dug in a springy spot, water being struck almost immediately, with a heavy flow at the bottom. Level varies somewhat with seasonal changes, but even in dry seasons is high.

20. Log shows coarse sand containing much water, beneath which is fine sand underlain by 6 inches of gravel, and clay at the bottom.

21. First 12 feet through gravel, which overlies 50 feet of quicksand that plugged the pipe and prevented inflow. The water horizon is in gravel below the quicksand.

47. Used for condensing ammonia in refrigerator. At 26 or 27 feet below surface is quicksand and below this clay.

49. Located near together and used to supply water for baths and swimming pool.

50. Driven in at sea level; water rises 10 inches in advance of the tide. The pipes, 40 in number, pass through 7 feet of tide water, 25 feet of soft blue mud, 6 feet of hard blue clay, 3 feet of material resembling hardpan, and 2 feet of mixed coarse and fine gravel, which yields the water. A pipe has been sunk 300 feet from the surface, passing through quicksand all the way below the gravel to bed rock.

64. Sunk through 5 feet of black and yellow loam and 16 feet of dark-colored hardpan with cobblestones, reaching rock here at 25 feet below the surface. One-half mile farther north is a second well, 15 feet deep, which passes through soft loam and quicksand and yields an abundance of soft water. Immediately to the east are wells, 10 to 12 feet deep, in gravelly soil. Toward the south the wells are in clay and hardpan.

66. One of a gang of five driven wells (two 6-inch and three 3-inch) supplying the town of Ridgefield. Another 6-inch well is 75 feet deep but of small yield, probably because it passes nearly through the water-bearing gravel.

70. Driven wells on gravel island in small lake. Temperature of water said to be 48° to 52° from February 15 to July, and from July to February will rise to 58° to 62°.

71. Said to have been drilled through hardpan, the water coming in several small veins.

73. Passes through thin layers of loam and gravel and at 12 feet into "closely packed broken rock."

76. Drilled 19 feet into rock, but the supply of water comes at the contact of the rock and the surface material.

81, 82. Said to have passed through sand, gravel, and clay, deriving their water from clay. A complete record of a well in the same vicinity gives 15 feet solid clay; 15 feet hardpan containing pebbles one-half inch to 3 inches in diameter; 41 feet gravelly dark soil; 29 feet bowlder material; 10 feet decomposed dry rock.

CHAPTER VII.

WATER SUPPLY OF TYPICAL AREAS.

WARREN—A HIGHLAND TOWN.

Warren is a typical highland town, with a population of 432, devoted to agriculture and allied interests. It has an average elevation of about 1,000 feet and an annual rainfall of about 50 inches. Mica schist (Berkshire) forms the bed rock in the western and southeastern parts of the town; gray banded gneiss (Becket) occurs at Cornwall Center; and granite occupies the northeast corner of the town on both sides of the west branch of the Shepaug. Glacial till forms a mantle over most of the rock surface and constitutes the principal water-bearing formation.

There are very few places in the town where abundant water is not found at a depth of less than 40 feet, and springs are numerous at low and high levels. In general, the farmers can choose between digging a shallow well and bringing water from a spring, as the cost of digging a 30-foot well is estimated to be the same as installing a pipe line 80 rods long. Mineral springs are not found in the town, and only one windmill is reported. The springs furnish soft water, the wells hard.

The following detailed information regarding the water supply of Warren has been furnished by Myron A. Munson. The numbers refer to locations on the accompanying map (fig. 27).

1. Spring sunk 4 feet, near the house; go for the water.

2. Water for house and barn brought from spring 50 or 60 rods east; soft, and excellent; running since 1852. Also well 14½ feet deep, water 7 feet; poor, apparently surface water mainly.

3. Water obtained from spring.

4. Well 16¾ feet deep; water 5 feet; good.

5. Well 21 feet deep; water 8½ feet; excellent, "soft for a well, makes good suds."

8. Well 15½ feet deep; water 7 feet; rather hard; use rain water also.

9. Well 19 feet deep; water very hard. There are two excellent springs at a distance of 20 and 30 rods.

10. Conditions not favorable for wells.

13. Three wells on the place. The one now in use is less than 20 feet deep. Water was formerly soft; coal ashes were deposited in some near-by depression, since which the quality of the water has deteriorated. The well is unfailing, and the supply so copious that it is difficult to exhaust the well sufficiently to prepare it for cleaning. "It would supply water for a hundred cattle." There are two springs on the place with water having a temperature of 48°.

14. Well about 12 feet deep; water is soft.

17. Water conducted from a spring.

18. Water brought from a spring on a lower level by means of a ram.

19. Water brought to house from spring, which is about 25 feet above the doorstep and 15 rods distant; 2 feet deep; fails in dry season. A second spring, supplying water to barn, boils up through sand and never fails; water is conducted to south barn. A third spring, of constant flow, supplies milk house and horse trough. A

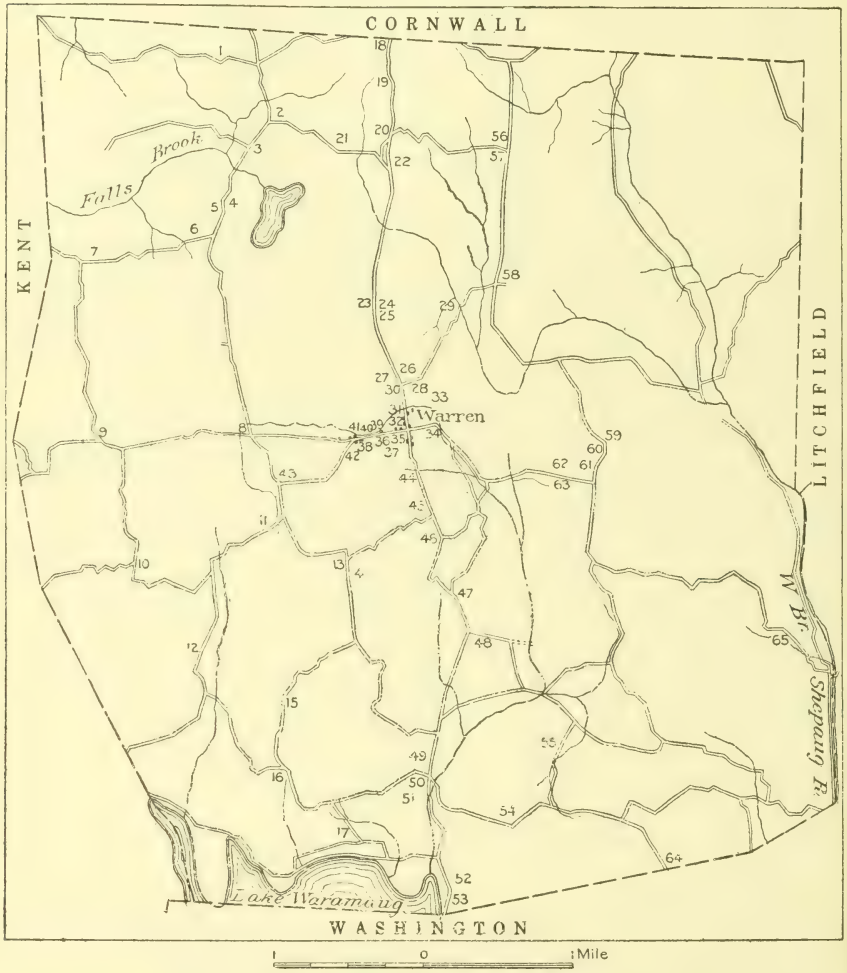


FIGURE 27.—Map of Warren, showing location of wells.

fourth spring, unfailing, is used only as pasture supply. Across the swampy meadow to the west is another good spring.

20. Rock ledge exposed; water formerly conducted from a spring. Conditions at the house are unfavorable for wells.

21. Well 18 feet deep; water 5½ feet; not very hard; two springs across the road supply milk houses.

22. Well 12 feet deep; water very hard. Spring at milk house across the road is declared to be "soft and sweet."

23. Well 19½ feet deep; water hard; rain water also used. Spring at milk house consists of three streams, which gush up from sand.

24. Obtains water from a spring in the field.

25. Supply similar to No. 24.

26. Has a "laundry spring" within 3 or 4 rods of the house; a better one 5 or 6 rods away; soft, and seldom failing.

27. Well 12 feet deep; water hard; rain water also used.

28. A good spring of soft water 5 or 6 rods distant from the house, "flowing as fast as can dip;" another colder spring is 4 rods farther away.

29. Well 38 feet deep; water 22½ feet; hard, and unfailing. At 50 rods down the hill to the northeast is an ice pond into which five springs flow. An unsuccessful attempt was made to bring an unfailing spring from a distance of a quarter of a mile. A windmill was installed at the well a few years ago but was later discarded.

30. Well 18 feet deep; water 9½ feet.

31. Well 16 feet deep; water 6¾ feet. Soft water is brought from a spring 30 rods distant.

32. Brings water in pails from an excellent spring of soft water at a distance of 8 or 10 rods.

33. This family obtains water from a good spring 30 rods distant.

35. Water rather hard.

36. Well 17¾ feet deep; water very hard, also contaminated. A new well about 12 feet deep at a distance of 15 rods obtained good water.

37. Well good; unfailing in driest times.

39. Well 13½ feet deep; water hard, yet suitable for washing.

41. Well 16½ feet deep; water said to be good.

42. Well 23¼ feet deep; water a little hard. Used for all purposes, though a little way east and west of the house are two soft springs. Is the "best in town." Never known to fail when drought was most severe.

43. Well 17 feet deep; water 7¼ feet; a little hard; rain water (cistern) also used. Excellent spring 70 rods to the northeast in corner of the orchard; another 150 rods to the southeast. Horse barn supplied from a well 10 feet deep, containing 6¼ feet of water. "The springs about here are soft."

44. Water carried from a spring near at hand, but at a lower level.

45. Well 15½ feet deep; water 6 feet; good. A spring in a swamp near at hand has been used.

46. Well 7 or 8 rods west of house, 15½ feet deep; contains 7½ feet of poor water. Water has been carried from the swamp named above (No. 45) into the cellar of this house, but the method worked poorly, and frequent repairing was necessary.

47. Water conducted from a spring at a considerable distance.

49. Water from spring at a distance of 40 rods.

50. Well 5 feet deep; water hard; unfailing.

51. Water brought from a spring sunk to produce a well of 12 feet depth; soft, good, and unfailing; has been used for fifty years.

52, 53. Two of six houses supplied from a spring on the hills to the east.

54. Unfavorable location for wells. Well measures 36½ feet, the "deepest in the town;" water 13 feet, but is "likely to become scant in the summer."

56. Well 20½ feet deep; water has an iron taste. A well 13¼ feet deep across the road in a corner of the barnyard is said to contain good water.

57. Well a few yards west of the house 16⅓ feet deep; water very hard. A number of good springs on lower ground.

58. Well 13½ feet deep spoiled by drainage from cesspool. There are six good springs, sweet and soft, on the place at no great distance, four of the six never failing. The house is supplied by two springs united, a quarter of a mile distant. A ram is employed.

59. Well 17 feet deep; water 12¼ feet; "soft as a spring;" sometimes fails.

61. Well 12 feet deep; water 6 feet; unfailing; soft, good for washing. Said on the spot to be the "best in town."

62. Well 10 feet deep; water 5⅜ feet, hard. Water is brought from a spring to this house and to the one across the road.

65. Spring of cold water issuing from a beautiful grotto; water is of uniform temperature throughout the year.

NORTH HAVEN—A LOWLAND TOWN.

The conditions surrounding the occurrence and recovery of ground water in the central lowland are illustrated in the town of North Haven, a portion of which is shown on the accompanying map (fig. 28). The area has an elevation of less than 100 feet and is underlain by sandstone, on top of which rest clays, sands, gravels, and till of glacial origin. Sand with large water capacity is the predominating surface formation. In the following descriptions the numbers refer to locations on the map:

1. Well 30 feet deep; contains about 4 feet of water. In sand and gravel the entire distance.

2. Well 30 feet deep; has 6 feet of water. In sand and gravel.

3. Well 30 feet deep, in sand and gravel; has 4 feet of water, "not very good."

4. A drilled well, 115 feet deep, all of the distance in sand and gravel.

5. Well 20 feet deep; has 4 feet of water. In sand and gravel.

6. One well 30 feet deep, with 5 feet of water; one 20 feet deep, with 6 feet of water; both in sand and gravel. There is also an excellent spring at this place, having a fall of 11 feet, which is sufficient to force water to all parts of the house. The ground water in the spring and in the shallow well appears to come from the northwest; that in the other well comes from the northeast.

7. Passes through sand, reaching rock at a depth of 20 feet. The water comes from just above the rock. The well is practically inexhaustible, three families using it all the time.

8. A large supply of good water from a well sunk 17 feet into sand. Has 7 feet of water.

9. Drilled in sandstone to a depth of 153 feet. Most of the water was reached at the 50-foot level.

10. One well is 16 feet deep in red sandstone and near at hand is another well or spring 9 feet deep in which the water is seen to bubble up through the sand at the bottom. One hundred barrels of water have been pumped from this spring at one time without exhausting the supply. Both wells are very close to Quinnipiac River.

11. Drilled well 45 feet deep; in rock for almost the entire distance. Gives an abundant supply of good water.

12. Drilled in red sandstone to a depth of 126 feet, most of the water being reached at a depth of about 45 feet; yields a good supply of water. A spring also occurs in the back yard.

13. Well 25 feet deep; walled with stone. After every freshet the sand pours in at the crevices so that it needs cleaning frequently. The water is excellent and abundant.

14. Well 15 feet deep; contains 5 feet of water. It does not fail, and the water is soft and good.

15. Well 16 feet deep; holds 8 feet of water. The water is very good, but fails in dry seasons. Spring 300 yards to the northeast gives an abundance of water for house use and is high enough to send water into all the rooms of the second story by gravity. There is also a spring at the barn.

16. Constant spring of good water.

17. Said to be about 20 feet deep.

18. Well 17 feet deep. The first few feet are in sand and the remainder in red sandstone, with a sharp easterly dip. The water occurs in the rock and varies but little with the seasons.

19. Well 22 feet deep; has about 4 feet of soft water.

20. Well 30 feet deep, the last 18 feet in red sandstone. The water found in the rock is soft and plentiful.

21. Well 30 feet deep, in sand and gravel. About 5 feet of soft water stands constantly in the well.

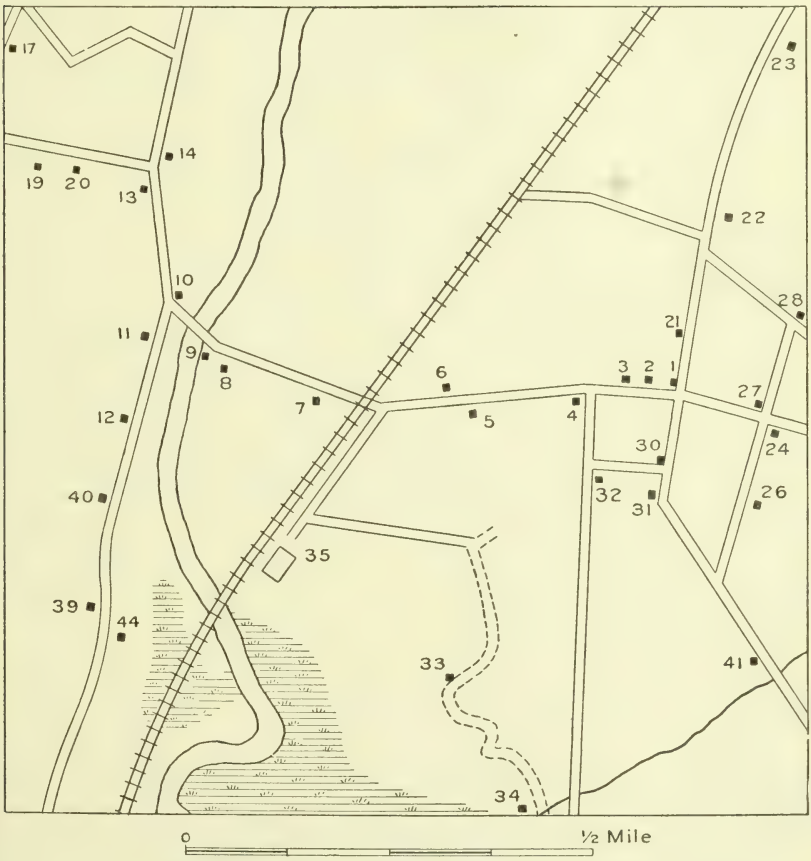


FIGURE 28.—Map of North Haven, showing location of wells.

22. Well sunk 35 feet in sand. Water is plentiful and not very hard.

23. Two wells; one at barn 25 feet deep with 3 feet of water; one at house 30 feet deep with 5 feet of water. Neither well runs dry.

24. Well 30 feet deep; has 5 feet of water. The first 25 feet are said to be in hardpan and the remainder in sand. Abundant water was found in the sand.

25. Well 30 feet deep. The first 25 feet are in the hardpan, then comes 2 inches of sand in which the water is found, and then about 4 feet more of hardpan. The water is plentiful, varies from 3 to 11 feet in depth, and is soft enough to be used continually for a laundry.

26. Drilled well 128 feet deep. It is reported that the first 84 feet are in sand and hard gravel and the last 44 feet in hardpan.

27. Drilled well 140 feet deep; derives water at depth of 100 feet, near contact of rock and till. Water is hard, rises within 25 feet of the surface, and does not vary in amount with seasons.

28. Well dug in hardpan to a depth of 44 feet. In the spring it sometimes contains as much as 15 feet of water. "This water will rust a tin in one night."

29. A very old well, dug and walled with brick; 45 feet deep; amount of water varies from 5 to 15 feet.

30. Dug well, 29 feet deep; contains 4 feet of water.

31. Dug to a depth of 45 feet in course gravel. Became dry during one season.

32. Dug to a depth of 12 feet in sand and gravel. It was dry once, but only for a short time. Ordinarily about 2 feet of water stands in the well.

33. Family gets water from a spring which issues at the top of a layer of clay.

34. Well 15 feet deep; has 2 feet of water. Walled with brick, but abandoned on account of surface contamination.

35. Drilled well, 195 feet deep; yields 8 or 10 gallons a minute. The first few feet are in sand, then comes about 50 feet of clay underlain by red sandstone. There are several recently drilled wells in this neighborhood, and their use has been followed by a great decrease in the number of cases of malaria.

36. Water for drinking purposes is brought from a spring which emerges at the contact of sand and clay.

37. Dug through sand and strikes a clay stratum at 13 feet.

38. Dug to a depth of 15 feet 6 inches, where it strikes sandstone; contains 7 feet of water and does not fail.

39. Dug in rock to a depth of 15 feet; contains about 7 feet of water.

40. Well on the hill is dug to a depth of "about 50 feet," the last 40 feet being in sandstone. At this same locality a shallow rock spring with insufficient water was converted into a satisfactory supply by drilling 10 feet into the rock.

41. Dug well 7 feet deep, the last 4 feet in red sandstone. The ground water is seen to come from the northwest.

42. Well at barn dug to a depth of 13 feet 6 inches, in sand and gravel; yields hard water. Well at house, in the cellar, is about 15 feet deep; passes through gravel to hardpan, where an abundant supply of soft water is procured.

43. Conditions same as at No. 42.

44. Drilled well in sandstone with a depth of "over 100 feet."

VICINITY OF BRANFORD POINT—A COAST REGION.

The region about Branford Point is fairly typical of the coast resorts along the Connecticut shore. It includes rocky knolls, stretches of sand flats and beaches, and expanses of marsh land. The bed rock of this area is gneiss, much broken by joints and planes of parting. The soil cover is till and beach sands. The insufficiency of supply and the danger of contamination by salt water have made it advisable to conduct water by pipe line from Branford River and to make this the chief supply. Two small springs are reported from this area.

The following descriptions accompanying the map (fig. 29) give detailed information regarding conditions which are typical of the water at Connecticut resorts.

1. Well 25 feet deep; contains about 5 feet of water, which is soft enough to make good suds.

2. Well has constant supply, medium in softness. It is 23 feet deep and contains 5 feet of water.

3. Well 24 feet deep; contains about 4 feet of water of medium softness.

4. Same depth and character as No. 3.

5. Well 27 feet deep; contains 3 feet of water.

6. One of the wells at this place is situated 5 feet from the edge of a salt marsh, but has never been known to become brackish. It is a driven well to a depth of 14 feet and contains 4 feet of water. The other well is sunk through glacial till, is 22 feet deep, and derives water from the contact of rock and till.

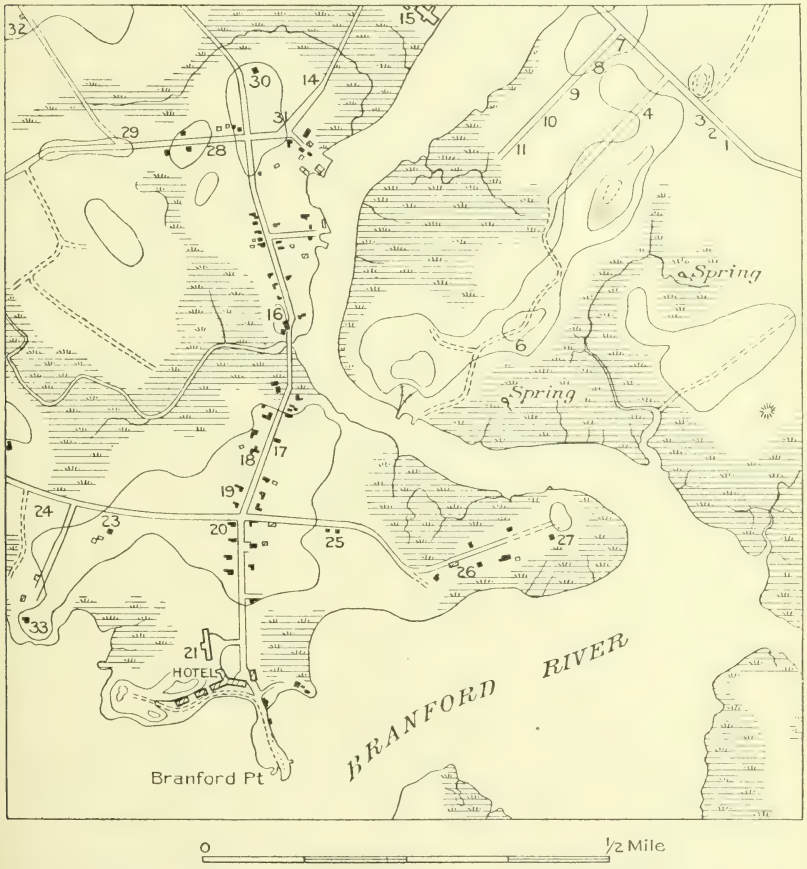


FIGURE 29.—Map of vicinity of Branford Point, showing location of wells.

7. A permanent well with water of medium softness; 32 feet deep; contains 4 feet of water.

8. Water said to be harder than in the other wells of the vicinity. The depth of the well is 33 feet and the water stands at 29 feet.

9. Well of hard water, 33 feet deep.

10. Dug to a depth of 25 feet; contains 4 feet of hard water.

11. Well 25 feet deep; has 4 feet of hard water; has never been known to fail.

12. Well 25 feet deep; has 4 feet of water.

13. Although situated very near the salt marsh and the tidal river, this well contains good water. It is 26 feet deep and has 3 feet of water. It has never failed.

14. This place is supplied by a well driven 5 feet below the cellar floor. Fresh water enters "like a spring" at the edge of the marsh.

15. This factory is located mostly on "made land" recovered from a salt meadow. Wells were brackish and were accordingly abandoned.

16. Well 12 feet deep; contains 1 foot 6 inches of water. Water became brackish and has been discarded in favor of city water.

17. Well 23 feet deep; contains a constant supply of about 3 feet of hard water.

18. Well 25 feet deep; contains 2 feet of hard water.

19. Well 25 feet deep; has 3 feet of soft water; yield regular.

20. Well 22 feet deep; has 3 feet of hard water.

21. Well at barn 15 feet deep; contains about 4 feet of water. City water used at house.

22. Well sunk in rock much broken by joints which permit access of salt water.

23. Well 25 feet deep; contains 2 feet 6 inches of water which is little affected by dry weather. Water is claimed to be soft and palatable.

24. Rain water is used because wells give brackish water.

25. Two driven wells in house, each 24 feet deep. One of these wells has yielded a good supply of soft water for twenty years.

26. On a narrow neck of land between two salt marshes and not over 20 feet from one of them; 16 feet deep; contains 3 feet of hard water.

27. Well 17 feet deep; contains 3 feet of water, which is wholesome but a little hard.

28. Well 23 feet deep; contains a constant supply of hard water.

29. Water is medium in softness. Well 25 feet deep, with 3 feet of water, and does not fail.

30. Well 22 feet deep; contains 2 feet of water of an unsatisfactory quality.

31. Well 24 feet deep; contains 3 feet of water of medium softness.

32. Well 25 feet deep; contains 4 feet of soft, wholesome water.

33. Well 16 feet deep, with 5 feet of water of good quality.

CHAPTER VIII.

CHARACTER OF GROUND WATER OF CONNECTICUT.

INTRODUCTION.

Pure water, as a compound of hydrogen and oxygen, is not known in nature. Descending rains take from the atmosphere considerable of its impurities and carry them to the ground; carbonic acid, sulphates and nitrates, especially near cities where coal is used for fuel, sodium chloride in the vicinity of the sea, and atmospheric dust contribute to the rainfall. Of the common gases rain water contains about 25 cubic centimeters per cubic meter, consisting of nitrogen about 64 per cent, oxygen 34 per cent, and carbonic acid 2 per cent. With the exception of chlorine, however, all the impurities of the air may be disregarded in the study of ground water.

After water enters the soil, it gathers materials from rocks and from decomposing organic matter. Sodium and potassium are taken from rocks containing feldspars. Calcium and magnesium are extracted from limestones and in less degree from rocks of other types. The minerals taken up by water in its subterranean course are chiefly silica, iron, aluminum, calcium, magnesium, sodium, potassium, chlorine, organic acids of uncertain composition, and the carbonate, bicarbonate, sulphate, and nitrate radicles. Barium, strontium, lithium, and other elements occur less commonly in appreciable quantity. Free carbonic acid gas is an ordinary ingredient of natural water, and oxygen, hydrogen, nitrogen, hydrogen sulphide, and hydrogen phosphide in solution are occasionally encountered.

As the value of water for any given purpose is determined by its composition, chemical study of surface and ground waters becomes a matter of great practical importance. The composition of ground water in Connecticut is of prime interest, because only the larger cities within the State receive their water supply from brooks or lakes. Of the 168 towns in the State 140 depend entirely on wells and local springs for their water supplies, and it is estimated that 40 per cent of the population obtain water for domestic purposes from more than 90,000 wells and springs.

COMPOSITION.

DETERMINING CHARACTERS.

The composition of the ground waters within the State is determined by the character of rock from which they are drawn. Shallow wells and springs in glacial drift contain substances leached from the upper soil and include nominal amounts of chlorine, sulphates, carbonates, nitrates, silica, calcium, magnesium, potassium, and sodium, with iron and aluminum in small amount, and a relative absence of organic matter. The deeper wells in the drift contain the same substances, but larger amounts of iron and less nitrates. Waters from glacial till and from rock are characterized by their relatively high content of calcium, magnesium, and sulphates. This is particularly true of water from sandstone and closely packed till or hardpan.

HARD AND SOFT WATERS.

As water takes up chemical compounds during its percolation through the ground, it often becomes what is commonly known as "hard" water, the term indicating its ability to form insoluble calcium and magnesium soaps when used for washing purposes. The greater proportion of the mineral constituents dissolved in shallow ground waters is obtained near the surface in what is known as the belt of weathering. This is the unsaturated zone between the ground surface and the level of the water table. The mineral constituents of this belt are relatively insoluble in their natural state, but they are continually undergoing oxidation, hydration, and carbonation, which result in the formation of compounds soluble in water. In the upper portion of the soil there is a large amount of organic matter which is oxidized through natural decay to carbonic and other acids. These acids, dissolved in water, attack the rocks and increase the mineralization of the underground supply. Calcium and magnesium in equilibrium with the bicarbonate radicle in water constitute temporary hardness, so-called because the minerals may be removed by boiling the water. If, however, the sulphate rather than the bicarbonate radicle is present the water is said to be permanently hard because boiling will not remove the dissolved minerals. The amount of calcium and magnesium present determine the relative hardness of water, and the proportions of the bicarbonate and sulphate radicles determine its character. The oxidation of iron sulphide is probably a source of sulphuric acid, which may decompose rocks with which it comes into contact. Among the most common constituents of crystalline rocks are silicates of iron, aluminum, calcium, and magnesium. These silicates in themselves are practically insoluble in water at ordinary temperatures, but in

the presence of waters containing carbon dioxide they are subjected to chemical changes and are carried away in solution.

There are many other methods by which water obtains mineral matter in solution, but those cited above are sufficient to illustrate the processes. It has been estimated by Reade[a] that for the entire earth there is removed annually in solution 96 tons of material per square mile, consisting of calcium carbonate, 50 tons; calcium sulphate, 20 tons; sodium chloride, 8 tons; silica, 7 tons; alkaline carbonates and sulphates, 6 tons; magnesium carbonate, 4 tons; oxide of iron, 1 ton.

MATERIAL TAKEN INTO SOLUTION.

Although there are many factors determining the character and the amount of the materials taken into solution by underground water, only two need be considered in this discussion. They are the character of the material traversed by the water, and the distance which the water has traveled underground. The waters of the glacial drift exhibit great variability of composition and are almost equally divided between hard and soft waters. In general the waters from the finely divided clay till are hard and those from the sand and gravel deposits are soft, owing to the character of the material. The sand and gravel deposits are composed largely of coarse grains of quartzose materials, which are dissolved with great difficulty by water, but the till is made up in part of masses of finely divided heterogeneous material which not only offer a more varied assortment to be acted on by waters but also give greater opportunity for solution owing to their fineness of grain. The deep-well waters of the sandstone are much harder than those of the crystalline rocks. In the latter the crevices afford the only passage for the water, and consequently the solvent action of the water is largely confined to the immediate walls of the crevices. In sandstone, however, the water traverses the entire rock, passing not only through the seams but also through the small pores between the grains, and thus has a vastly greater surface for action. Many of the sandstones of Connecticut are arkoses containing as great variety of mineral constituents as the original crystalline rocks.

In regard to the distance that the water travels, it is manifest that the longer and the slower the passage the greater opportunity there will be for solution. Increase of heat and pressure increases the solvent power of water; the waters which have penetrated deeply and have been subjected to great heat and pressure often have a larger proportion of dissolved minerals than those at shallow depths.

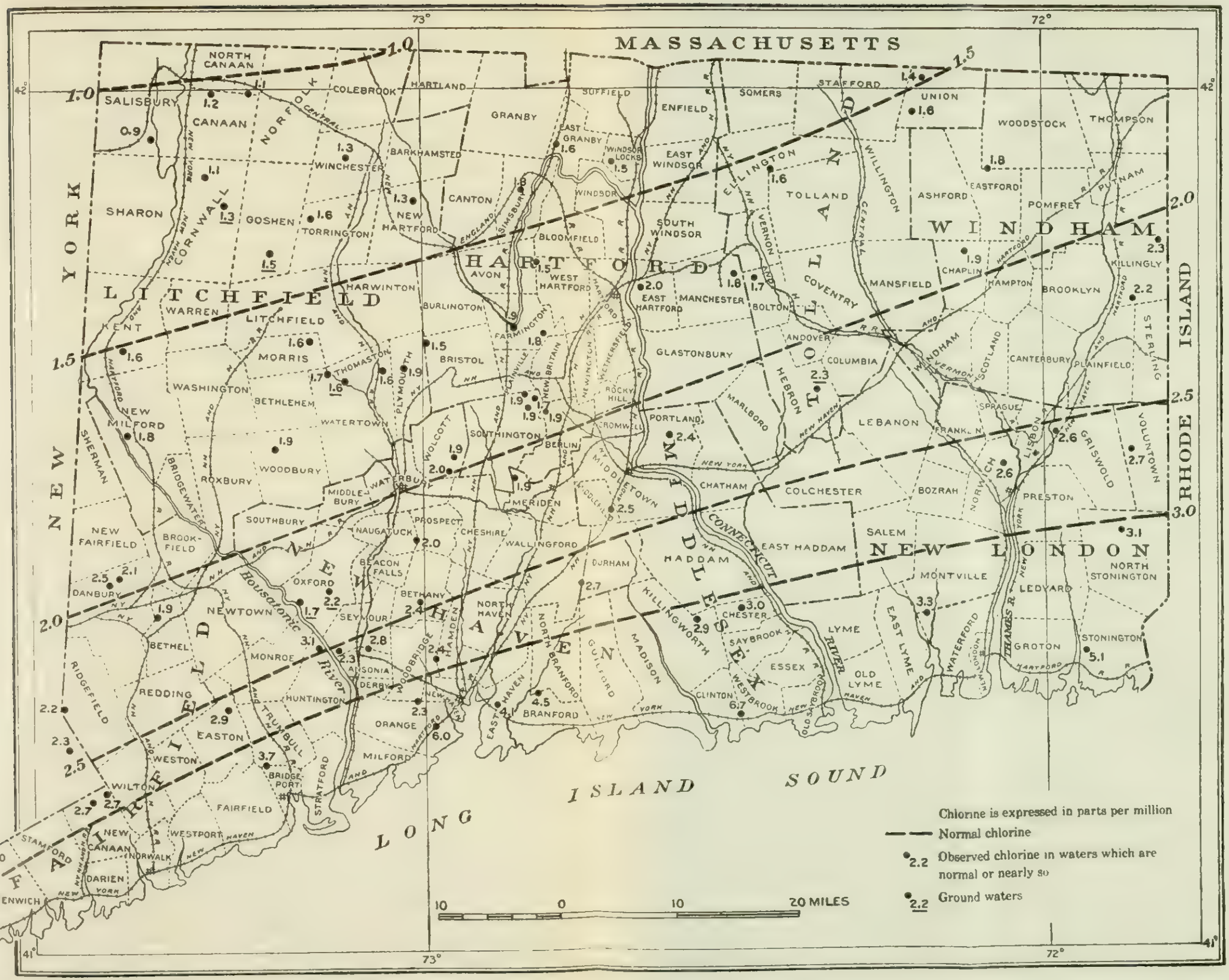
[a] Reade, T. Mellard, Chemical denudation in relation to geological time.

Analyses of waters from 13 wells in crystalline rock give an average of 132 parts per million of total solids. Analyses of 18 well waters derived from Triassic sandstone areas average 655 parts per million of solid matter. Exclusive of three well waters that contain over 1,000 parts of solid matter, the average for 15 well waters from sandstone is 377 parts per million. Five well waters from glacial drift average 263 parts of mineral matter. The analyses of 25 spring waters give an average of 73.5 parts of total solids. It is impossible to state from the available data whether springs from one source contain more mineral matter than those from a different source. The information at hand gives no indication of any definite increase of mineral matter with increase in depth of the well, and though there might be such increase in very deep wells, it seems that within the ordinary limits of well depth in Connecticut—between 100 and 500 feet—the relation of mineral content to depth has no practical bearing.

NORMAL DISTRIBUTION OF CHLORINE.

Chlorine, which is a constituent of common salt, is present in all natural waters and comes from salt deposits within the earth or from salt-laden spray from the ocean. In Connecticut there are no deposits of salt or other chlorine compounds from which waters might derive appreciable amounts of chlorine, but this substance is present in them in considerable quantity and the proportion of it in ground water decreases regularly with increase of distance from the coast. The obvious inference is that the natural waters obtain their chlorine from the minute particles of sea water that are blown inland by the winds. The amount of chlorine in normal waters of Connecticut has been determined for different parts of the State,[a] and a map prepared under the direction of Prof. H. E. Smith, of the Yale Medical School, indicates the normal distribution of chlorine by means of isochlors or lines defining the areas within which the waters in their natural state contain certain definite amounts of chlorine. (See Pl. V.) The value of knowledge regarding the normal distribution of chlorine is that it affords a ready basis for testing the purity of both surface and subterranean waters. Salt is present in all animal dejecta and eventually finds its way to the water courses, both above and below ground; consequently if a water contains more chlorine than the normal amount for the area in which it occurs, the presence of sewage or other contaminating matter may be suspected. Excess chlorine in wells immediately adjacent to salt water is not necessarily an indication of sewage contamination, but usually of the admixture of sea water.

[a] Rept. Connecticut State Board of Health for 1902, pp. 227-242.



MAP OF CONNECTICUT, SHOWING DISTRIBUTION OF CHLORINE.

USES OF WATER.

WATER FOR DOMESTIC PURPOSES.

The uses to which underground water is ordinarily put in Connecticut are relatively few in number. Owing to the ease with which large amounts of soft water are obtained, city supplies are usually taken from ponded reservoirs fed by surface drainage and by springs. For private residences and manufactories outside of cities, however, wells constitute the chief source of water supply for general purposes, and even in cities some manufacturing concerns find it expedient to use well water.

The three main purposes for which well and spring waters are used are for domestic supply, as in cooking, drinking, and washing, for boilers, and for coolers. A reasonably soft water is desirable for all these purposes and is particularly necessary in the case of boiler water, because hard waters form a scale in boilers, causing a heavy expense for additional fuel, cleaning of flues, extra firings, and boiler repairs. Soft water is preferable for general domestic use, though it is not so palatable as hard water. In breweries, distilleries, and other manufacturing establishments where a supply of cool water effects a great saving in artificial refrigeration, well waters are economical.

WATER FOR BOILERS.

Most of the large manufacturing establishments in Connecticut are on the banks of the more important streams, where abundant water for boilers may ordinarily be obtained from the heavy sand and gravel deposits that fill the major valleys. Such supplies are reasonably soft and cold and are satisfactory for cooling and boiler purposes, although frequently unsafe for drinking owing to surface contamination. Wells penetrating a considerable distance into the rock are preferable as sources of drinking water. Water from wells in the crystalline areas is usually soft enough for boiler use, but that in the sandstone areas is likely to be hard and is frequently disastrous to boilers. A study of Connecticut waters with regard to their availability for steaming purposes has been made by George H. Seyms, chemist of the Hartford Steam Boiler Inspection and Insurance Company, who has kindly allowed free use of his valuable data. Mr. Seyms has classified Connecticut waters in regard to their use in boilers, taking into account the average proportion of the different constituents in the normal waters of the State and assuming that one-half of the total solids is incrusting matter. Water containing less than 250 parts per million of solid matter is pronounced good. Water containing between 250 and 500 parts of solid matter is fair for boiler use, but if the amount exceeds 500 parts the water is unfit

for general boiler purposes. In making this estimate the fact has been taken into account that in most parts of the State supplies of soft surface waters may be obtained at reasonable rates. Increased hardness means increased cost of maintenance and where hard waters are used for boilers, as in the Western States, it is only because supplies of soft water are not available. The water supplies of Connecticut are recommended by Mr. Seyms for boiler purposes in the following order: (1) River waters (where uncontaminated by factory wastes); (2) ponded reservoirs; (3) small streams (as compared with rivers); (4) springs and shallow wells 30 to 50 feet deep; (5) deep wells. Wells in sandstone are less suitable as a source of water for boiler use than those in crystalline rocks.

CONTAMINATION.

INTRODUCTION.

That the ground water of Connecticut is liable to contamination and needs careful and frequent examination is well shown by the analyses of tainted waters made by the state board of health and by the typhoid epidemics which have occurred within the State. In 1893 the health officers of 119 towns reported on the condition of water supply,[a] and pronounced the water of only 82 towns unqualifiedly good. In 1898 analyses were made of water from 247 wells on the premises of public schools in the State; only half of them were free from suspicion of dangerous contamination and many were highly polluted.[b] In 1899 only three out of 14 suspected wells examined were declared safe.[c] In 1902 the water supplies of 101 hotels and restaurants and summer resorts were inspected, and only 20 out of 33 samples taken from springs, wells, and cisterns were considered safe.[d]

Sixty cases of typhoid, probably caused by water from a well 25 feet from a house, occurred in 1882 at Portland.[e] The drainage from a vault entering the quicksand caused typhoid at Guilford during the same year.[f] Water from a well in Middletown gave typhoid to an entire family in 1884.[g] The analyses of water from three wells at Madison in 1885 revealed the source of pollution which caused 14 cases of fever.[h] Contaminated water at Money Island caused 21 cases of typhoid in 1891.[i] The epidemic at Stafford in 1894 was traced to a polluted well.[j] The great epidemic at Stamford in 1895, in which 386 people were afflicted, was caused by milk delivered in cans which had been washed in well water infected by drainage from vaults.[k]

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[a] Ann. Rept. Connecticut State Board of Health, 1893, p. 110.
[b] Idem, 1898, pp. 279, 280.
[c] Idem, 1899, p. 21.
[d] Idem, 1902, pp. 223–226.
[e] Idem, 1882, p. 140.
[f] Idem, 1882, p. 144.
[g] Idem, 1884, pp. 79–81.
[h] Idem, 1885, pp. 342–344.
[i] Idem, 1891, pp. 205–213.
[j] Idem, 1894, pp. 232–238.
[k] Idem, 1895, p. 161.

Typhoid at Easton in 1895 was traced to a well adjoining a pig pen.[a] Thirty cases of typhoid in Glastonbury in 1895 were caused by a contaminated well at Hopewell.[b] An investigation of the typhoid at Ridgefield in 1901 showed that the entire ground water of an area covering several blocks had been contaminated by sewage.[c] The typhoid epidemic, 84 cases in all, at Bristol in 1903 was due to infected water from a farm well and spring.[d] Several less conspicuous occurrences of typhoid are likewise directly traceable to contaminated ground water.

"It is now universally recognized that the degree of prevalence of typhoid fever in a given community is a reliable measure of the extent to which sewage is an ingredient in its drinking water. The prevalence of typhoid in cities is a true index of the quality of the water supplies."[e]

The annual death rate from typhoid in Connecticut has been steadily decreasing, and this satisfactory record is due largely to the increased attention paid to the character of water supplies.

CONTAMINATION BY SEWAGE.

Sewage is the most widespread source of contamination of water in springs and wells. Drainage from vaults, cesspools, broken sewers, slops thrown on the ground, pig pens, and other sources of filth passes readily into the ground water and is the common vehicle for substances dangerous to health

LOCATION OF WELLS.

The location of a well is the most important consideration in obtaining pure water. The well should be placed at a considerable distance from any known source of contamination, on ground of relatively high elevation, and should be surrounded by an open, clear space, preferably grass covered. The direction of the flow of ground water for the area should be determined, if possible. Many wells in Connecticut are located in utter disregard of the simplest principles governing the movement of underground water. Instances might be cited where cesspools and other waste reservoirs are within 25 feet of wells used for domestic supply. For some wells the worst possible locations seem to have been selected. The writer has noted between 40 and 50 wells located on slopes below cesspools, in such manner that the contaminated waters, either in drift or in rock, are carried with certainty into the wells. It is not the depth but the location of a well which usually determines its purity, and a 20-foot well located with care may be much safer than a 100-foot well sunk without

[a] Ann. Rept. Connecticut State Board of Health, 1895, p. 90.
[b] Idem, 1895, p. 99.
[c] Idem, 1901, pp. 301-305.
[d] Idem, 1903, p. 88.
[e] Idem, 1899, p. 21.

regard to surrounding conditions. A good illustration of this is the well on the New Haven Green, a shallow well in the heart of the largest city of Connecticut. The quality of the water is good, because the surface about it is protected on the south and east by pavements and because its water is received from the Green, a grass plot 16 acres in extent, kept clean by the city authorities.

There is a general impression that soil will filter the impurities from water within a few feet of its source and that contamination of wells is due chiefly to material falling in at the top. No more dangerous error could be propagated. The purifying power of a soil is limited and it may easily be overburdened. In fact, the value of any soil filtration is uncertain, and it is impossible to state that water will be purified by passing through any amount of soil. The uncertainty is greatly increased by the existence of more or less open channels, which offer rapid passage to underground water with little filtration.

DEPTH AND CONSTRUCTION OF WELLS.

Shallow wells are much more likely to become contaminated than deep wells, and as probably 80 per cent of all wells within the State are less than 25 feet in depth, the importance of care in their maintenance is evident. There is in Connecticut, particularly in the rural districts, a strong prejudice in favor of the shallow, open well and a belief that clear, sparkling, palatable water is sure to be pure. The danger in these beliefs is very real, for certain parts of sewage tend to give water a sparkle which is highly appreciated by those unacquainted with its character. Drilled or bored wells have many advantages over shallow dug wells. There is less chance for foreign substances to drop into the well, and it is possible to shut off all surface and seepage water. The "old oaken bucket" has sentimental advantages, but iron pipes and creaking windmills are much better symbols of the purity of drinking water.

CONTAMINATION IN DIFFERENT ROCK TYPES.

Contamination of water in shallow drift wells has been the cause of many typhoid epidemics in Connecticut, as at Bristol, Easton, Glastonbury, Guilford, Madison, Middletown, Portland, Ridgefield, Stamford, and Stafford. The water supply at Camp Coffin was found to be contaminated in 1896 by water that collected in a pool used for washing clothes and reached the well by sinking through a considerable depth of sand and gravel. In 1903 the Chamber of Commerce of New Haven made an investigation of the local water supply, which led to the recommendation that all wells within the city should be abandoned as sources of water for domestic uses. The wells examined are mostly in till or stratified drift, range in depth from 20 to 220 feet,

and are located in all sections of the city. Six samples were taken from wells 20 to 30 feet deep, eight from wells 30 to 50 feet deep, five from wells 50 to 100 feet deep, and nine from wells over 100 feet deep. The committee reported that, with the exception of a few samples from the outskirts of the city, all showed evidence of a past contamination in a more or less marked degree. In Hartford, Waterbury, and other cities analyses of water derived from sand and gravel deposits commonly indicate considerable sewage contamination, although the water is obtained at points 30 to 50 feet below the surface. In fact, it is doubtful if any well is safe in a thickly settled community.

Spring water may likewise become contaminated by sewage-laden ground water, as illustrated at Forestville and South Norwalk during the typhoid epidemics of 1900.[a]

Though drilled wells are much less subject to sewage and drainage contamination than shallow-dug wells of large diameter, equal care should be taken in their location. A number of deep wells have been drilled in the low central portion of Hartford, and many of them show heavy contamination in waters supposed to be derived more than 200 feet below the surface. This is a portion of the city which received for years a large amount of drainage, so that whatever water enters the rock through the soil carries with it considerable contaminating material. Some of this water finds a ready passage through more or less open joints and enters the wells. The contamination of many such wells results from imperfect casing and the consequent entrance of water from the surface. There is little doubt that in certain wells imperfect joints allow shallow waters to enter the well at the contact of the rock and the drift. Such poor construction may be due to carelessness, or to intention, owing to the desire of the driller to obtain a sufficient supply of water. The entrance of any water at the junction of the casing and the rock may be detected if a mirror is used to reflect light into the well.

That contaminated water may circulate through considerable distances of sandstone is shown by the experience of Hartford, already described. At the Wallingford Sanitarium a well was contaminated by gasoline which flowed through the bedding planes of rock for a distance of 225 feet at a depth of 8 feet below the surface. Many similar cases might be cited.

Even wells sunk in granite and other crystalline rock are not free from contamination by circulating water. The typhoid epidemic at Sachem Head was caused by drinking water from a well blasted in rock to a depth of 16 feet. It was shown that the contaminated water passed through joints for a distance of 6 feet. At Millstone

[a] Ann. Rept. Connecticut State Board of Health, 1900, pp. 274–285, 286–289.

Point brackish water was seen to be supplied from a rock seam at a distance of 150 feet. Part of the ground water of Fishers Island is known to come through crystalline rock from the Connecticut mainland, 3 to 4 miles distant.

CONTAMINATION BY SEA WATER.

The Connecticut wells which have been contaminated by sea water are within 200 or 300 feet of open salt water, on old salt marshes, along tidal streams, or on islands. They are practically all in rock where the surface water has presumably been entirely cased off. The surface water, however, is usually fresher than that derived from the rock itself. In a well drilled for the Norwalk Iron Works Company, Norwalk, at an elevation 10 feet above sea level, fresh water was found in sand and gravel deposits at a depth of 60 feet, but salt water only was obtained at lower levels in the rock. The well was accordingly plugged at a depth of 60 feet and the rock water excluded. At many points along the coast pipes have been driven in deposits

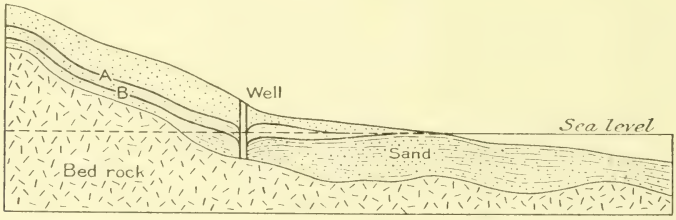

FIGURE 30.—Diagram illustrating the manner in which a well near the sea may be contaminated by salt water during the dry season. A, normal water table; B, depressed water table.

of sand and gravel near the shore and abundant supplies of fresh water have been obtained. These wells may, however, receive increments of salt water when the water table is brought below sea level, either by pumping or by dry seasons. In deep-driven wells near the shore which derive their supplies from the bottom of closed tubes, the head of fresh water is almost without exception sufficient to prevent the inflow of brine. In New Haven a series of wells have been driven through 6 feet of salt water into the sand deposits below and have obtained good supplies of fresh water.

In wells deriving water from rock in which the supply necessarily comes through fractures it is possible that the fractures may have such position as to give more ready access to sea water than to fresh underground waters. The possibility of contamination by this process increases rapidly with nearness to the sea, especially if the rock outcrops beyond the shore line. Figure 30 represents the direction of circulation of water contributing to such well, the ground water above the rock being entirely cased off.

RELATIVE VALUE OF WATER SUPPLIES.

Experience has shown that water in Connecticut is to be recommended for domestic use in the following order: (1) Surface supplies, preferably from lakes that are constantly under supervision and subjected to frequent inspections and examinations; (2) deep wells so located that the surface area contributing to them is known to be free from contamination; (3) springs, especially deep-seated ones, like those along fault lines known to derive their water from regions not subject to contamination; (4) shallow wells and intermittent springs; (5) lakes and streams whose character has not been carefully determined.

ANALYSES.

In the following tables of analytical results the data are given in ionic form, in parts per million, having been recomputed, if not originally expressed in that manner. The column headings are in general self-explanatory. "Total solids" indicates the total dissolved matter found by evaporating a measured quantity of water and weighing the dried residue. "Organic and volatile matter" represents the difference in weight between the dried solids and the solids after being ignited at low red heat; the figure serves as a rough measure of the organic matter, though it also represents loss of water of crystallization, volatilization of some inorganic constituents, and other factors. The term "total hardness" is given to a figure found by adding standard soap solution to a measured amount of water till the mixture forms a good lather when shaken vigorously; the equivalent of the quantity of soap consumed is usually expressed as calcium carbonate ($CaCO_3$). The "permanent hardness" is found by adding soap solution to water that has been boiled and filtered; it represents the hardness due to calcium and magnesium in equilibrium with acids other than carbonic acid. The "temporary hardness" is estimated either by subtracting the permanent from the total hardness or by titrating the water with normal acid.

Analyses of well waters from crystalline rocks.

[Parts per million.]

No.[a]	Analyst.	Hardness as $CaCO_3$.		Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Organic and volatile matter.	Soluble residue.
		Total.	Alkalinity.													
10	Unknown	95											234	570		
18	H. Southern Eng. Co	97	60		Trace.	31				71	18		22	193	9.1	
26	Unknown	36											9.4	126	10	
40	E. E. Smith	36	28		Trace.							4.0	4.0	69	9	
57	Unknown	26			Trace.							.4	22	132	14	
58	S. P. Wheeler				1.9			58			17		7.0	[b] 84		
59	G. H. Seyms							High.					High.	12,013		11,925
102	H. E. Smith			18	.9	15	1.8	10		59	13	3.1	4.0	95	6.4	
133	S. P. Wheeler	63											25	212	12	
177	H. T. Vulté	11	11									Trace.	9.3	106	6.0	
(c)	H. E. Smith		48									.3	9.7	202	8.0	
(d)	do		62									.2	4.3	102	12	
185	G. H. Seyms							High.					High.	1,052		868
[e]185	do							High.					High.	4,746		4,668
192	Unknown											5.3	6.0	124	24	
198	G. H. Seyms										High.		High.	308		232
208	Levi Wilcox				Trace.	21							13	138	80	
[f]208	do					19							26	203	75	
204	Unknown	60										.7	1.2	122	17	
209	State chemist	140											34	347	39	
210	G. H. Seyms													268		192
211	Levi Wilcox	101										11	28	297	116	
227	G. H. Seyms										High.		High.	4,056		3,852
[g]227	do										High.		High.	208		176
233	H. E. Smith	35										.9	2.8	48		
237	do	30										.2	2.6	68	10	

[a] The numbers refer to the well records on pp. 78-89.
[b] Trace of lithium.
[c] Well of C. I. Hempstead, Glenbrook, Stamford; drilled 140 feet; 80 feet in rock.
[d] Well of Stamford Water Co., Stamford; 247 feet deep.
[e] Seven months later than first analysis.
[f] Same well at depth of 122 feet.
[g] Same well after one year's constant use.

Analyses of well waters from sandstone.

[Parts per million.]

No.[a]	Analyst.	Hardness as $CaCO_3$.		Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Organic and volatile matter.	Soluble residue.
		Total.	Alkalinity.													
8	Unknown			20	15	[b]326	[b]106	118	(b)	(b)	1,201		213	2,524	410	
(c)	H. E. Smith	48										2.6	5.0	100	8.5	
15	G. H. Seyms													112		84
26	do					High.	High.				High.			316		224
(d)	do													288		164
(e)	do										High.			536		332
(f)	do										High.			2,312		1,256
(g)	do									High.				816		368
69	H. E. Smith	240	96								430	.4	13	628		
74	Unknown			18	.7	146	31	90			469	9.2	22	941		
(h)	G. H. Seyms													156		108
85	H. E. Smith			19	2.0	330	9.9	24			802	.2	3.7	1,296	57	
(i)	G. H. Seyms					High.					High.			376		284
112	Unknown	274			Trace.	82	41			150	164			722		
(j)	G. H. Seyms					High.	High.				High.			2,580		1,848
117	H. E. Smith	52				10						12		110	9.0	
152	do	28										.4	2.0	69	5.0	
165	Unknown			14		44	11	5.5		116	54		8.5	258	62	
189	do	110											10	241		

[a] The numbers refer to the well records on pp. 116–123.
[b] Carbonates of calcium and magnesium, 54 parts; trace of lithium (Li) and the phosphate radicle (PO_4).
[c] Well of Mount Carmel Bolt Co., Mount Carmel, Hamden; dug 35 feet deep and 30 inches diameter.
[d] Well of Billings & Spencer Co., Hartford; drilled 250 feet
[e] Well of G. W. Brown, Linden Building, Hartford; drilled 235 feet.
[f] Well of Hartford Woven Wire Mattress Co., Hartford; 250 feet deep; water at 200 feet; flow, 15 gallons a minute.
[g] Drilled well of Long Bros., Hartford.
[h] Well of Goetz Bakery, Manchester; drilled 200 feet deep in soft brownstone.
[i] Well of Charles Parker, Meriden; 1,000 feet deep.
[j] Well of Tuttle Brick Co., Newfield, Middletown; drilled 264 feet.

Analyses of well waters from stratified drift.

[Parts per million.]

No.[a]	Analyst.	Hardness as $CaCO_3$.		Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Organic and volatile matter.	Soluble residue.
		Total.	Alkalinity.													
45	Unknown					74	11				26	28	44	404	48	
50	T. B. Osborn			12		31	30	85		170	83		105	528	98	
(b)	G. H. Seyms					High.								368		212
56	H. E. Smith	134											26	298	30	
(c)	Unknown				Trace.	36	Trace.	9		72	30		13			

[a] The numbers refer to the well records on pp. 152–155.
[b] Well of National Folding Box and Paper Co., New Haven; 2-inch test well 100 feet in gravel.
[c] Well of Waterbury Brass Co., Waterbury; 35 feet deep.

Analyses of well waters from till.

[Parts per million.]

Well.	Analyst.	Hardness as $CaCO_3$.		Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Organic and volatile matter.	Soluble residue.
		Total.	Alkalinity.													
(a)	H. E. Smith	21										1.8	2.6	79	15	
(b)	Unknown	54										2.2	5.9	107	15	

[a] Well of R. K. Jones, Turnerville, Hebron; dug 16 feet deep.
[b] Well of W. E. Bond, New Canaan; dug.

Analyses of spring waters.

[Parts per million.]

No.[a]	Analyst.	Hardness as $CaCO_3$.		Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.	Organic and volatile matter.
		Total.	Alkalinity.											
1	Unknown	43									8.8	6.0	94	23
4	R. H. Chittenden			18	0.3	4.0	1.1	4.0	15	8.0		1.5	45	
8	H. E. Smith			14	.2	2.4	1.1	3.1	14	1.8	.2	1.2	34	2.7
9	C. A. Seitz			25	14	12	9.0	116	323	5.6		2.6	346	2.2
19	H. E. Smith	22	18								2.6	2.5	50	7.5
23	S. P. Wheeler			6.0	1.2	2.1	1.4	14	12	1.3		18	50	
(*b*)	H. E. Smith	73	59								2.2	2.0	101	14
32	Unknown			9.5	1.0	10	6.0		58	1.6		1.3	61	
34	R. B. Riggs			7.2	Trace.	4.4	.4	6.7	17	3.5		5.4		
(*c*)	H. E. Smith	16	13								.1	2.5	37	11
(*d*)	do	23									3.7	3.2	60	11
(*e*)	do	58	47								1.1	3.7	72	12
(*f*)	do	36	30								.4	3.1	63	7.5
(*g*)	do		8.0								.0	1.0	22	8.0
55	do	23									.7	3.3	93	
(*h*)	do	44	40								3.0	3.1	62	10
62	Unknown											4.0	72	22
63	G. F. Barker			23	11	6.0	2.2	5.0	17	29		3.6	107	24
65	Unknown	20									9.7	2.0	52	16
(*i*)	H. E. Smith	42	38								1.5	4.3	72	18
69	R. H. Chittenden	7.0		10	.2	3.0	1.0	3.5	13	2.4		2.6	38	8.0
66	E. S. Sperry			6.3	.4	2.2	1.0	7.3	10	9.1		3.1	42	8.0
*j*74	Unknown			34	13	5.1	.3	12	6	14		3.2	122	29
83	H. E. Smith			11	.8	8.3	2.6	8.7	26	11	8.0	7.3	71	
90	S. P. Wheeler	28											56	20

[a] The numbers refer to the spring records on pp. 191–194.
[b] On Whitman place, at Farmington.
[c] Spring of J. V. Palmer, Millville, Naugatuck.
[d] Cherry Hill Spring of H. B. Gorham, Highwood, New Haven; from sandstone.
[e] Spring of Mrs. D. Auger, Fair Haven, New Haven.
[f] Spring of Stillman Water Co., near East Rock, New Haven.
[g] Spring of G. H. Bush, Norfolk.
[h] Quinnipiac Spring of L. R. Hemingway, North Haven.
[i] Spring of Z. Chaffee, Pomfret.
[j] Phosphates present.

CHAPTER IX.

WELL CONSTRUCTION IN CONNECTICUT.

DUG WELLS.

The common type of well in Connecticut is naturally the most primitive type—an excavation in the ground to a depth below the level of ground water, the interior being lined with brick or stones. These wells are usually dug in clay, sand, and glacial drift, but a few, where the surface material is shallow, are blasted into the underlying rock. Some wells are dug into rock and water is obtained from crevices, but in general the rock excavation serves merely as a reservoir for water draining from the drift. Such wells are usually 2 to 4 feet in diameter inside the stone casing and from 10 to 50 feet in depth.

Very few dug wells are properly constructed in Connecticut and many are extremely old, it being not unusual to find wells sunk more than a hundred years ago. The ordinary stone casing is very inefficient as a protection against the entrance of surface water, the openings between the stones being in many wells large enough to permit the passage of rats and other small animals. Brickwork is used as a lining in some of these wells, but probably the safest method of protecting such a well against contamination is by tiling.

Too much care can not be taken in the location and protection of open, shallow wells. A well of the open type containing clear, sparkling water has been considered one of the most valuable possessions of home. Such wells are, however, peculiarly liable to dangerous contamination. Many of them are located on low ground, because water may be procured there at less expense, and some are walled up with poorly cemented stone and either open or covered only with loose boards. The tops of many of these wells are but a few inches above the level of the ground and may readily serve as resting places for impurities carried by wind or on the feet of animals and men.[a] The advantages of the small drilled or bored well, as compared with a dug well, are the decreased probability of the entrance of impurities at the time the well is put down, less opportunity for rats, frogs, and other animals to enter the well, and the ease of shutting out surface and seepage waters. It can not be too plainly stated that open wells are dangerous to health.

[a] See a discussion of this subject by Crider, A. F., and Johnson, L. C., Water-Supply Paper U. S. Geol. Survey No. 159, 1906, pp. 74–75.

As dug wells usually reach but a few feet below the level of ground water, any fluctuations of the water table materially affect the yield of the wells. In dry seasons the water table may sink below the bottom of the well, with a consequent total loss of supply. This loss of supply, owing to drought, is more noticeable in wells located on hills than in those along stream channels.

Dug wells are of value in rural communities, but in cities and thickly populated areas they are extremely unsafe because of the general contamination of the soil and the impracticability of keeping out surface water.

The average cost of a well of this type, as ordinarily constructed in Connecticut, is about one-fourth to one-half that of the average drilled well, but when it is carefully constructed and cased so as to admit water only at the bottom, the cost is not far from that of a well constructed on more sanitary principles.

DRIVEN WELLS.

For wells in sand and gravel a method of well construction is recommended which, although commonly used throughout the United States, is little appreciated in Connecticut. This is the driven well, consisting essentially of a pipe, usually 1 to 2 inches in diameter, driven into the ground by means of a heavy weight. These pipes are perforated near the base either by boring round holes or by cutting straight slits with beveled inside edges. In some wells the perforated pipe is fitted with a jointed conical tip; in others a hollow open tube is fitted with a perforated section of some noncorrosive material and a sharp steel shoe, so that it can be driven directly into the ground. The contents of the tube are then washed out by water. As the water can enter the well only through the perforations, the position of the base of the pipe determines definitely the depth at which the water enters a well of this type, thus differing radically from a dug well, in which more or less water enters from top to bottom. Such wells are usually put down in a connected series known as "gangs," all connected with a central pipe or main through which the water is pumped. In very favorable localities large supplies may be obtained in this way at relatively small expense. There are several such gangs in New Haven; one of 34 wells at the Yale gymnasium which supplies the swimming pool with 150 gallons a minute was driven at a cost of $600. Another gang of wells furnishes the Yale dining hall with water for cooling, and 40 such wells, each with a diameter of 2 inches, are used by the Hygienic Ice Company.

Wells of this type can be driven only into unconsolidated material, where the water horizon is in sand or gravel. Many places in Connecticut are favorably situated for obtaining water from driven wells,

particularly those towns along the main river valleys and near the coast where the sand deposits are heavy. The average cost of such wells is 70 cents a foot and the yield and character of the water obtainable at any place may be readily and cheaply ascertained by means of a single test well costing not more than $20 or $25.

The quality of the water obtained from driven wells is largely determined by their location in reference to possibility of sewage contamination. Although derived from greater depths the water from driven wells of moderate depth is not necessarily better than that from dug wells situated in the same contaminated district, for the flow of ground water through sand and gravel is more rapid than through till, in which the dug wells are commonly constructed. In thickly settled communities the water of driven wells often shows contamination. There are many localities where unpolluted waters may be obtained by driven wells and this method of construction is advised for the Connecticut Valley lowlands, where larger yields and softer quality may generally be obtained from drift than from the underlying sandstone.

DRILLED WELLS.

Of the various methods of obtaining supplies of underground water, drilled wells should probably rank first in importance. Although the most expensive, they are most free from contamination and yield the most constant supplies.

As the process of drilling wells is not generally familiar, it seems advisable to present a brief statement of the methods employed in Connecticut. The two main methods of well drilling are known as churn drilling and rotary or core drilling, the former being far the more common. A churn-drilling rig includes a movable boiler and engine mounted on a frame which is ordinarily drawn by horses or by traction. Attached to the front of this rig is a collapsible derrick which acts as a support for the rope and tools used in the drilling operation. The drilling tools consist of a heavy steel bit, with other devices, such as jars and sinkers, which serve to prevent wedging of the bit, to add weight to the blow, etc. The bit is supported by the rope, and by means of a walking beam or other device is lifted and allowed to drop suddenly 20 to 30 inches, giving a succession of blows at the rate of 25 to 40 a minute. The sharp edge of the heavy bit breaks and crumbles the rock where it strikes, and by continually twisting the supporting rope the bit is made to strike a new spot each time. The result is a round and even hole with a diameter slightly greater than the width of the bit. The diameter of the drill hole is usually 6 inches, although 8-inch wells are not uncommon.

Owing to the presence of glacial drift, a layer of sand or gravel or till is usually traversed before the drill strikes rock. The unconsoli-

dated material carries more or less "surface water," which it is desirable to exclude. To accomplish this purpose, the careful driller inserts a casing, consisting of heavy iron pipe with water-tight joints. The iron casing should extend from the surface to bed rock, and it is particularly important that a tight joint be made where the casing meets the rock. This junction should always be examined by means of reflected light from a mirror to detect the presence of any surface water. Water is kept in the hole during drilling operations, and after every few feet of progress the tools are removed and the well cleaned out by means of a "sand bucket," a hollow tube with a valve at the bottom.

As the chief water horizon in drift is at the contact of rock and the overlying material, it is important to know the character of the rock mass encountered. This is not always easy to determine, for it is not an uncommon occurrence to strike large bowlders that lie many feet above the bed rock and may be readily mistaken for solid ledge. The driller may assure himself in this regard by drilling into the supposed ledge. If it is a bowlder he will pass entirely through it in the course of a few feet. Moreover, the nature of the rock will ordinarily indicate whether it is part of the underlying strata or a fragment carried from a distance.

The rate of drilling, or number of feet a day, varies widely with the character of the rock, and the price charged for drilling is ordinarily regulated by the driller's knowledge of the bed rock in the locality. In crystalline rocks—to which the drillers generally apply the term "granite"—the rate varies between 2 and 25 feet a day. The price for drilling in crystalline rocks varies between $2.50 and $8 a foot, the average being $4.25 a foot. In such wells the same rate is charged for the surface material as for the rock, but the driller furnishes the casing without additional expense. In sandstone drilling is much easier and the average price charged is about $2 a foot for a 6-inch well. For an 8-inch well the price is 50 to 75 cents a foot additional. The average drilled well costs more than a dug well and much more than a driven well, but it possesses advantages not shared by the other types.

Core drilling or "diamond drilling" has been employed with considerable success by one contractor in the western part of Connecticut. In this process the drilling tool consists of a rapidly rotating pipe, the end of which is edged with diamond fragments, chilled steel, or other sharp cutting material which wears away the rock below the cutting edges and leaves a cylindrical core within the pipe. This core is broken off and removed by various devices, leaving a hole of the desired diameter.

Drilled wells are far safer in sanitary respects than either of the other types considered. The process of construction is such that

with proper care the surface water may be entirely cased off and a supply obtained from a sufficient depth to insure safety. It should not be forgotten, however, that fissured rock may have openings large enough to allow the passage of water without adequate filtration; this is much more likely to occur where the rock outcrops in the vicinity of the well than where a mantle of glacial drift overlies the ledge. In one place near New Haven where the soil was only 2 feet deep, gasoline leaking from a buried tank at a distance of 150 feet entered the rock and was carried into a drilled well at a depth of at least 18 feet. The gasoline may have entered the well through a crevice or by percolation through the rock itself. Although the contamination of deep-drilled wells is possible, it is an unusual occurrence and is generally due to imperfect casing.

A dishonest driller may sink a deep hole into dry rock and arrange the casing in such a manner that the water from the soil and the upper surface of the rock enters and fills the hole, giving the appearance of a yield from a great depth. The water is large in amount and may show a satisfactory analysis. Sooner or later, however, the ground water establishes channels of ready circulation and any contamination from surface water may enter and penetrate to the bottom of the well.

To give a minimum possibility of contamination the following points should be observed: The well, of whatever kind it may be, should be located as far away from and as high above sources of contamination, like cesspools, open sewers, and barnyards, as circumstances permit; the well site should be selected where the glacial drift above the rock is deep, rather than on a thinly covered rock or on bare ledges; the well should be properly cased—a point to which too little attention is paid in constructing either dug or drilled wells. The driller usually furnishes casing from the surface to the rock, but where circumstances indicate that more casing is needed for safety the owner should not hestitate to assume the slight extra expense required to insure absolutely safe construction.

CHAPTER X.

SPRING WATERS.

INTRODUCTION.

If the surface of Connecticut were level and the soil of uniform composition and texture, the ground water would tend to assume a plane surface at a small distance below the cover of soil. Such a water table would rise and fall with each increase and decrease in precipitation, but there would be no well-marked channels to conduct ground water to the surface. Connecticut, however, is a region of topographic inequality and variability of soils and bed rock and the imprisoned waters find many avenues of escape.

The normal outlet for ground water is near the level of lakes, swamps, and rivers, where it emerges in large amounts although rarely in definite channels. Below the earth's surface there are innumerable openings from which water is poured unnoticed into streams, lakes, or marshes along the shore line where salt water mingles imperceptibly with fresh. If the floor of Connecticut River were exposed suddenly to view by removing the water, we should see tiny rills issuing from cracks and seams and porous places in the rock and drift forming the river bed.

To speak broadly, any definite outlet for ground water is a spring, regardless of its size or of the geologic conditions which surround it.

TYPES OF SPRINGS.

There are springs which emerge from the ground with a force to turn mill wheels and with a volume to float a river steamer. There are springs which come from great depths and furnish vast quantities of hot water. The springs of Connecticut are of another kind—small and widely distributed, containing cold water of exceptional purity, and those suitable for domestic purposes and local supplies are to be numbered by the thousand.

The three types of springs commonly found in the State may be classed as seepage springs, stratum springs, and fault or joint springs.

SEEPAGE.

Many hillsides and lowlands bordering streams and ponds are saturated with moisture and the ground is soft and springy under the foot. This is especially noticeable during the early part of the year, when ground water is particularly abundant. These marshy places

are "seeps" and are caused by ground water returning to the surface from the rocks beneath. Such diffused seepage, rather than drainage along definite channels, is the normal method for the escape of water from the ground, and, in fact, it is only where this return seepage is concentrated by some local geologic conditions that a stream issues from the ground as a spring.

When seepage is restricted to a limited area it may form a seepage spring, in which the water slowly escapes from sands or gravels over a space of a hundred square feet, more or less. In its natural state a seepage spring is marked by the presence of water-loving plants and in many places also by the presence of an oily-looking scum or film on the water, which is often mistaken for petroleum but which in reality is the result of decomposing vegetation. The particular factors which have served to concentrate the water at this place are not always easy to determine, but ordinarily a slight difference in texture of the sands or the presence of a thin mantle of drift over rock is sufficient to bring the water to the surface. As a rule the water can be still further concentrated by digging a hole or sinking a barrel into the ground in the zone of most vigorous seepage, thus furnishing a small local reservoir which receives the ground drainage from a larger area.

There is, of course, no sharp line between general diffused seepage, seepage springs, and springs proper, although the term "spring" ordinarily implies a distinct stream of water issuing with some force from an opening a few inches or, at most, a few feet in diameter. No distinct channel need be exposed at the surface, but there must be at hand a definite horizon or zone along which the circulation of ground water is sufficiently rapid to form a constant stream of appreciable size.

STRATUM SPRINGS.

The horizon most suitable for the transmission of large amounts of water is the plane between strata of different degrees of permeability. In such positions the water occupies a definite zone in some porous stratum and is confined by strata through which it passes with difficulty. A stratum spring may originate between two sedimentary beds, between drift and underlying rock, between clay and sand, or even between sands of slightly different structure. Where the edges of water-bearing strata are exposed at the surface, as in stream valleys or in artificial sections, the water is allowed to escape and soon tends to excavate channels along which further progress is rapid.

Where an impervious bed overlain by porous strata is exposed for long distances, a line of springs may be formed at the contact between the strata. Lookout and Raccoon mountains, in Tennessee, are bordered by a fringe of springs which reach the surface at the contact of the capping sandstone with a prominent bed of shale. In the

Snake River canyon, Idaho, a line of springs of great volume emerges from sedimentary beds underlying lava. The edge of the North Haven plain in Connecticut is marked by numerous springs. This sand plain is underlain by clay which forms a basement bed for the ground water, and where the beds are truncated by Quinnipiac River springs emerge from the bedding plane between the clay and the overlying sands. Similar conditions are reported from the Po Valley of Italy, where the water penetrates the sand and remains underground for several miles, finally emerging as a long line of springs where the water table is forced to the surface by more pervious beds. Probably 75 per cent of the springs in this State owe their existence to the concentration of water between beds of sand, clay, till, and rock.

FAULT AND JOINT SPRINGS.

Ground water occupies all open spaces within the earth's surface and moves along joints and faults and seams as well as between beds of stratified series. The rock walls forming the two sides of a fault are usually sufficiently separated to allow the passage of water and the fissure is usually of sufficient depth to permit a profound circulation. Ground water from a large area may be contributary to a single fault zone and may exert pressure sufficient to drive the water along the crack with considerable power. Most of the famous hot springs of the world are located on fault lines. Many small springs in Connecticut are located along faults;[a] their temperature, however, indicates that the water in them does not come from very great depth.

TEMPERATURE.

The temperature of the ground below a depth of 50 or 60 feet is not affected by daily or seasonal changes at the surface, and the temperature of water which comes from those depths is therefore subject to only slight variation, remaining at about 47°, which is the average annual temperature of the State. No hot springs are reported from Connecticut, and temperatures under 45° are rare. Of the springs recorded on pages 191–194 only five have temperatures less than 45°, and none over 55°. The well-known Arethusa Spring at Seymour has a temperature of 47°, which coincides with the average annual temperature of the State. In a nonvolcanic region like Connecticut the temperature affords some indication of the depth from which water comes, and the absence of high temperature implies that even in fault springs the occurrence of water is relatively a surface phenomenon.

It is frequently reported that the water from springs is colder than normal in summer and warmer in winter. These statements, however, are not borne out by the facts.

[a] See map by W. H. Hobbs, in Water-Supply Paper U. S. Geol. Survey No. 67, 1902, p. 80.

INTERMITTENT SPRINGS.

If Connecticut received a uniform and evenly distributed rainfall and were forest covered, the springs of the State would be practically permanent in position and constant in yield. The rainfall, however, is not uniformly distributed, the region is partly woodland and partly farms, and the strata consist of many varieties of rocks and soil. The result is that some springs are constant, some vary in yield, and some cease entirely during parts of the year. The flow of a spring is much more constant than the rainfall, because water in rocks is absorbed and stored much more rapidly than it escapes, and the rainfall from a large area returns to the surface through a few channels. The soil is a reservoir filled within a few hours and then allowed to drain off for several weeks. In Connecticut the supply of water in the soil is usually renewed by rain before the reservoir is emptied, and the springs are kept flowing at varying rates of speed.

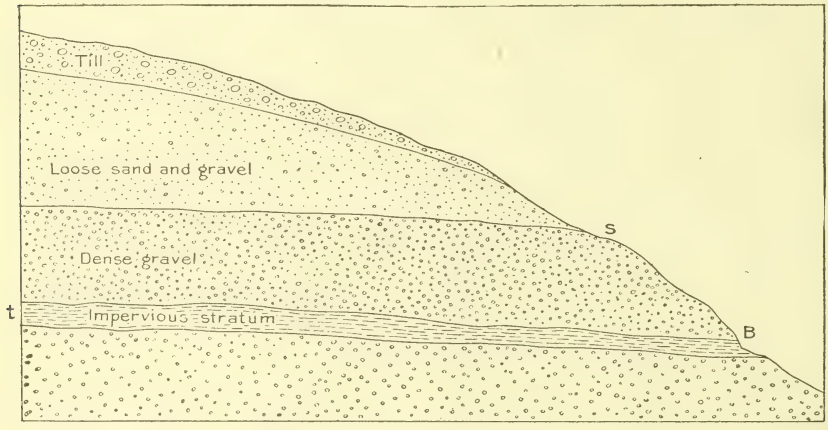

FIGURE 31.—Diagram illustrating conditions for intermittent spring. For explanation, see text.

The fact that ground water returns to the surface gradually is the chief factor which insures permanency of flow and carries springs and rivers through periods of drought. In certain parts of the country the principal supply for rivers is furnished by ground water, and during parts of the year the only water which enters Connecticut brooks is supplied by springs and seeps.

A spring which normally gives a continuous flow may become intermittent during dry seasons. The hill shown in figure 31 consists of sand and till, which allows water to be absorbed in large amounts and to sink to the impervious stratum along which ground water flows to the surface as a spring at B. When the water stands at "S," temporary springs may form, which cease to flow when the water's level drops to "t." In unusually dry seasons the water table may sink below the second outlet, thus producing an intermittent spring from one that has been constant for several years.

MINERAL SPRINGS.

All springs contain mineral matter in larger or smaller amounts, but its presence may not affect the color or odor or taste of the water. In a popular sense, mineral springs are those which are notable for the large amount of their mineral content, for some conspicuous characteristic of the water, such as color, odor, or taste, or for the presence of unusual mineral ingredients considered to be of therapeutic value. Dissolved rock material is sometimes deposited about the mouths of springs in quantities amounting to several tons a year. Even the ordinary cold-water spring carries to the surface appreciable amounts of rock. It has been estimated that the combined activity of 900 ordinary springs in the eastern part of the United States results in piling up each year rock enough to form a block 10 feet square and 2 miles long.

Several springs in Connecticut are reported to have medicinal value. Many springs, however, pass as medicinal merely because they have a forbidding odor or taste, and prove on examination to have little in their favor. It hardly needs to be stated that disagreeable characteristics are no evidence of the therapeutic value of water. There are no springs in Connecticut with an unusual abundance of rare mineral constituents, and few that are conspicuous because of their color and odor.

VOLUME OF SPRINGS.

Springs vary in size from minute trickling rills to streams that give rise to small brooks. The amount of water in a spring depends directly on the available supply from which it is drawn, and this in turn is directly related to the amount of rainfall and to the size of the area which is contributary to the spring. The attitude and structure of the rock are also important considerations. The rock may be stratified, may have open bedding planes of wide extent, or may be dense and massive. Its texture may be coarse or fine. It may be easily soluble or resistant to chemicals. Furthermore, the distribution of farm and forest land and the relative position of hills, plains, and valleys have much to do with collecting water and guiding it along the channels leading to a spring.

USES AND PRODUCTION OF SPRING WATERS.

The chief use of spring water in Connecticut is for domestic purposes. Thousands of houses are supplied by springs, either in their natural state or covered and connected with pipes, and some small villages derive a large proportion of their common supply from such sources. Springs are so abundant and so widely distributed that most farm houses have spring water either directly at hand or easily obtainable by a short pipe line.

The dairying industry requires large amounts of cold water flowing regularly through the cooling rooms, and Connecticut is highly favored in this regard.

Fifteen springs report sales of table water for 1908 and there are known to be many others which have more or less local use. About nine-tenths of the production is sold for table purposes. One spring is the site of a resort with accommodations for about 80 people. During 1908 the output of water increased about one-third and the value decreased one-seventh as compared with the record for 1907. The sale of water from 15 springs for 1908 was 424,826 gallons, at an average price of 9 cents a gallon.

The springs from which water was sold during 1908 are enumerated in the following list:

Althea Springs, near Waterbury, New Haven County.
Arethusa Spring, Seymour, New Haven County.
Aspinock Mineral Springs, Putnam Heights, Windham County.
Buttress Dike Spring, Woodbridge, New Haven County.
Cherry Hill Spring, Hamden, New Haven County.
Crystal Spring, near Little River, Middlesex County.
Elco Spring, Bristol, Hartford County.
Glenbrook Spring, Glenbrook, Fairfield County.
Granite Rock Spring, Higganum, Middlesex County.
Highland Spring, near Mount Higbee, Middlesex County.
Hillside Spring, Meriden, New Haven County.
Live Oak Spring, Meriden, New Haven County.
Mohican Spring, Fairfield, Fairfield County.
Oxford Mineral Spring, Oxford, New Haven County.
Park Spring, Norwich, New London County.
Pequabuck Mountain Spring, Bristol, Hartford County.
Quinnipiac Springs, Montowese, New Haven County.
Red Rock Spring, Meriden, New Haven County.
Rock Ledge Spring, New Haven, New Haven County.
Stafford Mineral Spring, Stafford Springs, Tolland County.
Varuna Spring, Stamford, Fairfield County.

RECORDS OF SPRINGS.

The following table and notes include the available statistics in regard to Connecticut springs:

Records of springs in Connecticut.[a]

No.	Town.	Locality.	Owner or authority.	Location.	Yield per minute.	Temperature.	Variation in flow.	Quality.	Source reported.	Use.	Remarks.
					Gallons.	°*F.*					
1	Ansonia		T. W. Sanford	Steep hillside	25		Less in summer	Soft, iron	Crystalline rock.	General, sale.	Rockland Spring; occasionally becomes milky after heavy rains. See analysis, p. 179.
2	Avon	Collinsville	Mrs. F. Konold	Hillside				Soft	Rock	Supply for water company.	
3	Bethel		Gilbert Bros				Less in dry weather.	do	Gravelly loam.	Domestic	Seeps out gradually; supplies 12 families.
4	Bristol		Mrs. E. G. Fitzpatrick.		(*b*)	42	Constant	do	Gravel	Sale	Pequabuck Mountain Spring. See analysis, p. 179.
5	Canterbury	Parkerville	Susie E. Witter	Hillside	2		Less in dry weather.	do		Domestic	
6	do	South Canterbury.	Henry Baldwin	Slope	Large.				Gravel		Spring was dry several years and reappeared in a new location.
7	Canton	Canton Center.	C. R. Hamlin								Locality abounds in gushing springs.
*8	do		W. E. Simonds's estate.	Base of hill	75	49½	Constant	Soft	Crystalline rock.	Sale	Massacre Spring. Dug out, staved, and covered. See analysis, p. 179.
9	Chatham	Middle Haddam.	H. S. Hurd	Slope				Soft, chalybeate.	do		Hunts Iron Mountain Spring; dug and staved to a depth of 12 feet. See analysis, p. 179.
10	do	Cobalt	C. B. McLean	Base of hill	(*c*)	50	Constant	Medium soft.	do	Domestic	
11	Chester		B. Harwood	Hillside	2	42		Hard		dc	Carries brown sediment.
12	do		First Baptist Church.	Near base of hill.	(*d*)		Less in dry weather and ceased once.	Soft	Crystalline rock.	do	Flat taste similar to rain water.
13	do		Moses Joy	Hillside	Large.	55	Constant	do			
14	Columbia		S. B. West	do				do		Stock	Water seeps out.
15	Cornwall	Cornwall Bridge.	C. W. Everett		(*e*)					Domestic, hotels.	55,000 gallons shipped weekly to New York.
16	Danbury		J. E. Walsh	Base of hill			Less in summer		Crystalline rock.	Domestic	Seeps out and collected in reservoir.
17	do		Danbury Spring Water Co.	Hillside	(*f*)		Constant			do	Seeps out; supplies 40 families.
18	do		Chas. Hull estate	Base of hill				Soft		do	Supplies 20 families, each 80 gallons per day.

[a] Additional details concerning springs marked with an * are given on p. 195.
[b] 4-inch pipe.
[c] 1-inch stream.
[d] ¼-inch pipe.
[e] 4-inch stream.
[f] 5,000 gallons per day.

Records of springs in Connecticut—Continued.

No.	Town.	Locality.	Owner or authority.	Location.	Yield per minute.	Temperature.	Variation in flow.	Quality.	Source reported.	Use.	Remarks.
					Gallons.	°*F.*					
19	Derby		John T. Cullen	Slope	3	46–52	Less in very dry summer.	Soft, charged.	Crystalline rock.	Sale	Spring is housed in; water retailed. See analysis, p. 179.
20	Ellington		Wm. H. Prescott	Hillside				Soft		Stock	
21	do		Francis M. Charter	Valley	10			Medium soft.		Domestic	
22	Fairfield	Westport	Marion B. Williams.		10		Constant		Crystalline rock.	Drinking	Gives yellowish deposits.
23	do		Mohican Spring Co.	Hillside	15		do		Rock, gravel, dry.	Sale	Mohican Springs; series of springs along a hillside. See analysis, p. 179.
24	Goshen	Milton	Elbert S. Richards	Base of hill	Large.	46	Less in dry season.	Soft	Sand	Domestic, stock.	Water is warmer in summer.
25	do	West Goshen	S. A. Bartholomew	Hillside	Large.		Never failing	do		do	
26	do	do	H. G. Wright	Valley	(*a*)	55		Soft, iron		Domestic	
27	Hartford		Francis Goodwin	Hillside		53	Constant	Hard	Gravel	Drinking	
28	Kent	South Kent	Don C. Peet	do	Large.	48		Soft	Rock		
29	Lebanon		C. W. Martin	do				Soft, iron	do	Drinking	
30	Libson	Jewett City	E. F. Burleson	Hilltop	(*b*)		Less in dry weather.	Soft	Clay	do	
31	Meriden		Chas. Parker Co	Valley	14	51		Soft, iron	Sandstone	Sale	Live Oak Spring; dug, walled, and covered.
32	Middletown	Highland	W. E. Wilcox	Slope	8	50	Nearly constant.	Soft	do	do	Highland Spring; dug and tiled. See analysis, p. 179.
33	Milford		Morton Grinnell	Valley		45	Constant	Hard	Gravelly sand.	Domestic	Supply for Milford Water Co.
34	Montville	Uncasville	Chas. S. Johnson	Base of bluff		50	do	Soft	Sand	Sale	Shantok Spring; constant temperature throughout year. See analysis, p. 179.
35	do	do	Eliza D. Geer	Base of hill				do	do		
36	do		Solomon Lucas	Hillside	17		Constant	do		Drinking	
37	New Britain		W. N. Dunham	Base of hill	8	48					Dug to depth of 4 feet.
38	do		American Hosiery Co.	Valley	750			Hard	Gravel	Bleaching, general factory use.	Dug out 30 feet deep and 15 feet diameter.
39	New Canaan		W. C. Clarke	Hillside	3			Slightly hard.	Sand	General	Water is collected in a cement reservoir.
40	New Hartford	Nepaug	Austin Beckwith	do	(*c*)			Soft, with iron and sulphur.	do		Carries a red sediment resembling iron rust.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 233

WATER RESOURCES

OF THE

BLUE GRASS REGION, KENTUCKY

BY

GEORGE CHARLTON MATSON

WITH A CHAPTER ON THE

QUALITY OF THE WATERS

BY

CHASE PALMER

WASHINGTON
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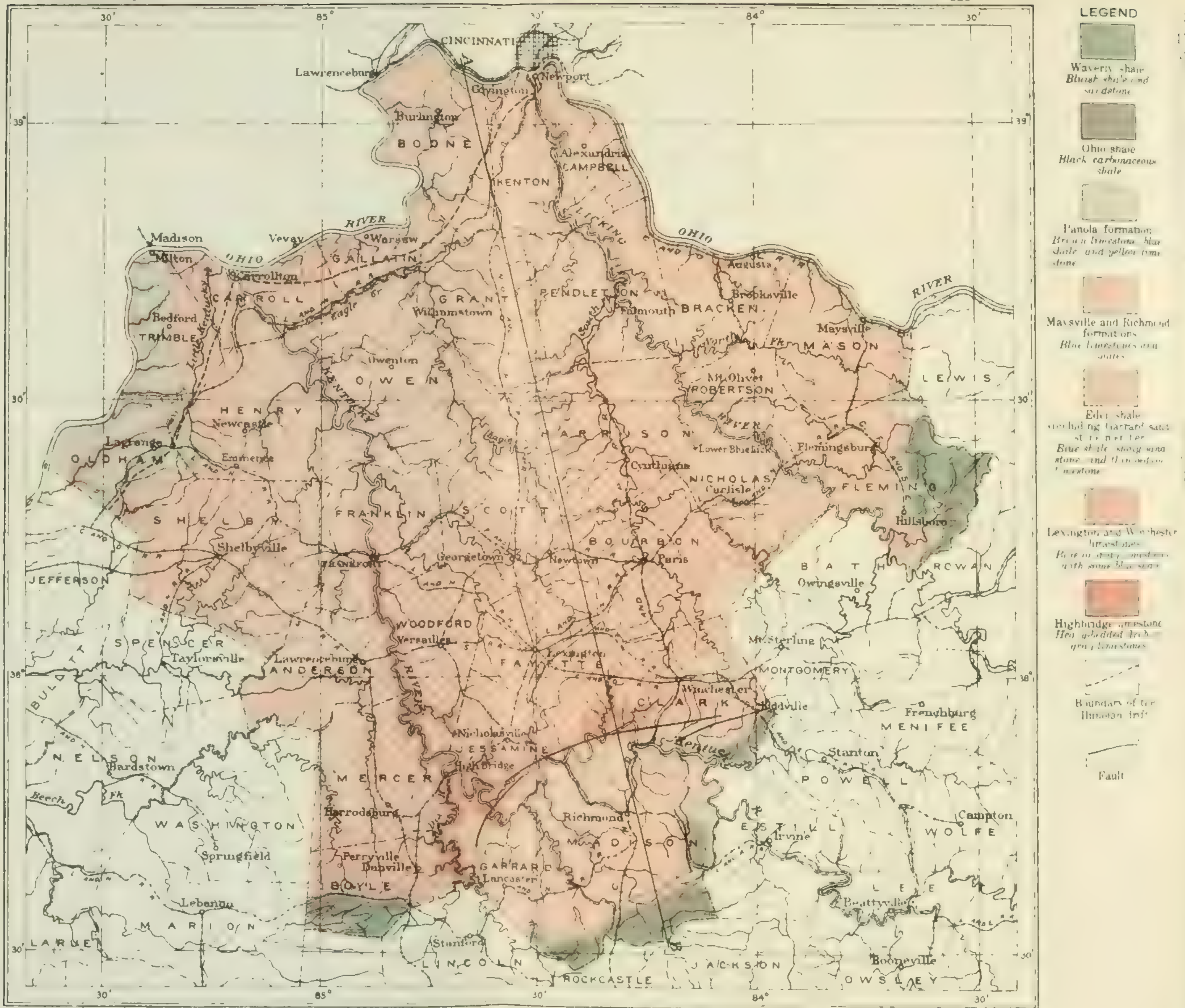

GEOLOGIC MAP OF THE BLUE GRASS REGION, KENTUCKY

SECTION ALONG LINE A-B

WATER RESOURCES OF THE BLUE GRASS REGION, KENTUCKY.

By George Charlton Matson.

INTRODUCTION.

The area described in this report comprises about 7,225 square miles in northeastern Kentucky, lying between parallels 38° and 40° north latitude and meridians 83° and 86° west longitude. It includes the major portion of what is commonly known as the "Blue Grass region," together with small areas of the more mountainous portions of the State, and covers the following counties: Anderson, Boone, Bourbon, Boyle, Bracken, Campbell, Carroll, Clark, Fayette, Fleming, Franklin, Gallatin, Garrard, Grant, Harrison, Henry, Jessamine, Kenton, Madison, Mason, Mercer, Nicholas, Oldham, Owen, Pendleton, Robertson, Scott, Shelby, Trimble, and Woodford. It is bounded on the north and west by Ohio River; on the east and south by portions of the boundary lines of the marginal counties. (See Pl. I.)

Geographically the Blue Grass region forms part of the Appalachian Plateau, which extends from the eastern edge of the Allegheny Mountains and the Cumberland Plateau westward to the Mississippi lowlands. Because this part of the Appalachian Plateau is drained by Ohio River, Campbell[a] suggested that it be called the Ohio Basin. The northwestern boundary of the Ohio Basin was regarded as extending from Mississippi River near Cairo across Illinois, Indiana, and Ohio to the west end of Lake Erie.

No systematic study of the occurrence of underground water in Kentucky was made prior to the summer of 1906, when such work was assigned by the United States Geological Survey to the author of this paper, who completed field and office work within the following year; but it should not be inferred that no earlier observations were made. Numerous references to the occurrence of water are found in the early reports of the State Geological Survey, by Dr. David Dale Owen. Underground waters, especially the mineral springs of the region, are discussed in some detail in the reports issued while Prof. N. S. Shaler was state geologist. Many observations on the mineral springs of Kentucky were made by W. M. Linney while John R. Proctor was

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898, p. 1.

state geologist. Since the beginning of the present Kentucky Geological Survey, of which Prof. Charles J. Norwood is director, the underground waters have been studied by Prof. Arthur M. Miller and others, and a recent report by Prof. August F. Foerste discusses the waters of the Silurian and Devonian formations of the east-central part of the State. Chemical studies of Kentucky waters were begun about the middle of the last century by Dr. Robert Peter, chemist of a university at Lexington, Ky., and when the first Geological Survey of Kentucky was organized Doctor Peter was appointed its chemist. After his death he was succeeded by his son, Dr. Alfred M. Peter. Any adequate discussion of the work done by these men is impracticable; the magnitude and great value of the work will be evident to all who examine the various reports of the Kentucky Geological Survey and the Kentucky Agricultural Experiment Station.

In 1904 Dr. Chase Palmer began a chemical study of the waters of Kentucky, Salt, Dix, and Green rivers. This work was continued in 1905 and Doctor Palmer then extended his investigations to the underground waters of the State. The results of part of his work are presented in the chemical chapter which forms part of this report. Incidental references to the water resources are found in all the histories of the State, but the most important publications about the water resources of the Blue Grass region are the various reports of the Geological Survey of Kentucky and the annual reports of the Agricultural Experiment Station. The information in regard to the quality of the water is especially voluminous. This information consists largely of analyses made by Dr. Robert Peter, chemist of the first and second geological surveys of the State, and his son, Dr. A. M. Peter, chemist of the Kentucky Agricultural Experiment Station. A part of the information given in the state reports has been compiled for publication in this paper, but most of it is in such form that it can not readily be arranged for presentation. A list of the principal reports dealing with Kentucky waters is presented herewith, and to these publications the reader is referred for further information.

LIST OF PAPERS CONTAINING INFORMATION IN REGARD TO KENTUCKY WATERS.

Geological Survey of Kentucky.
David Dale Owen, director.
Report for 1854–55. 1856.
Second Report, for 1856–57. 1857.
Third Report, for 1856–57. 1857.
Fourth Report, for 1858–59. 1861.
N. S. Shaler, director.
Reports of Progress, 1874–75, vol. 1, new series, 1876.
Reports of Progress, 1877, vol. 2, new series, 1877.
Reports of progress, 1877, vol. 3, new series, 1877.
Report of Progress, 1878, vol. 4, new series, 1878.
Report of Progress, 1880, vol. 5, new series, 1880.

Geological Survey of Kentucky—Continued.
John R. Proctor, director.
Geology of Garrard County, by W. M. Linney. 1882.
Geology of Mercer County, by W. M. Linney. 1882.
Geology of Clark County, by W. M. Linney. 1884.
Geology of Mason County, by W. M. Linney. 1885.
Geology of Fleming County, by W. M. Linney. 1886.
Geology of Henry County, by W. M. Linney. 1887.
Geology of Shelby County, by W. M. Linney. 1887.
Geology of Oldham County, by W. M. Linney. 1887.
Chemical analyses, A, 1884, by Robert Peter, chemist, and John H. Talbot and A. M. Peter, chemical assistants.
The first, second, and third chemical reports of the Geological Survey of Kentucky; reprinted from vols. 1, 4, and 5, new series.
Chemical report, A, vol. 2, 1885, by Robert Peter, chemist, and A. M. Peter, assistant chemist.
Contains the fourth chemical report of the Geological Survey of Kentucky; reprinted from vol. 5, new series (pp. 5–93).
Chemical report, A, vol. 3, 1888.
C. J. Norwood, director.
The oil and gas sands of Kentucky, by J. B. Hoeing. Bull. No. 1, 1905.
The lead and zinc bearing rocks of central Kentucky, by Arthur M. Miller. Bull. No. 2, 1905.
Chemical report of the coals, clays, mineral waters, etc., of Kentucky, by Robert Peter. Bull. No. 3, 1905.
The Silurian, Devonian, and Irvine formations of east-central Kentucky, with an account of their clays and limestones, by Aug. F. Foerste. Bull. No. 7, 1906.
Kentucky Agricultural Experiment Station.
First Annual Report. 1888.
Seventh Annual Report. 1894.
Eighth Annual Report. 1895.
Tenth Annual Report. 1897.
Eleventh Annual Report. 1898.
Twelfth Annual Report. 1899.
Thirteenth Annual Report. 1900.
Fourteenth Annual Report. 1901.
Fifteenth Annual Report. 1902.
Sixteenth Annual Report. 1903.
Seventeenth Annual Report. 1904.
Eighteenth Annual Report. 1905.

HISTORICAL SKETCH.

The pioneers of Kentucky entered the State through the mountain passes to the east, bringing with them, perforce, the barest necessities of life, and were compelled to rely on game for a large part of their food supplies. These early settlers found that certain saline springs were frequented by large game, and that these springs or the traces (trails) leading to them formed the best hunting grounds.

The sites of Boonesboro (founded by Daniel Boone) and Harrodsburg, the first settlements in the State, were chosen because of their proximity to good springs, and one of the springs near Boonesboro furnished salt water, which doubtless attracted deer and other wild

animals. The same reason determined the location of scores of the early settlements and nearly all the important cities and towns of the State. Some of the Kentucky springs, such as Bryant Station Spring and Lower Blue Lick Spring, were later made famous in connection with the struggles of the settlers against the Indians, and still later large springs formed objective points for the armies of both Bragg and Buell.

Practically all the old mansions of the Blue Grass region were built where spring water was accessible, but when the inhabitants began to build houses upon the divides many wells and cisterns were dug. Doubtless the disastrous cholera epidemics of the first half of the eighteenth century stimulated the digging of cisterns, and during the last generation many have been constructed. In favorable localities the drilled wells have largely supplanted the dug wells, but they will probably never supplant the cisterns.

The early industrial enterprises of the Blue Grass region consisted of mills and distilleries, many of which relied upon springs for their water supplies; but with the development of the country, the establishment of new routes of travel and new centers of trade, and the enlargement of the industrial enterprises, the spring supplies became inadequate and many of them have been abandoned. At the present time much water for industrial use is drawn from streams or wells, although springs continue to hold a very important place, and in some localities drilled or driven wells are used.

As already indicated, the villages grew up about springs from which each family drew enough water for its individual needs; but when the villages came to install public supplies, they commonly sought either well or surface water, until at present only one city, Georgetown, takes its water supply from a spring. While it has usually proved impracticable to use either wells or springs for municipal supplies, many of the smaller towns have public wells or springs which furnish water for a number of families.

NEED OF THE INVESTIGATION.

The great need for definite information in regard to the water resources of the country has long been evident to both practical and scientific men, and in the Blue Grass region the subject has keen interest for sanitarians, householders, manufacturers, and civic communities.

In Kentucky, as elsewhere, the occasional outbreaks of water-borne diseases, such as typhoid fever, have emphasized the necessity of obtaining pure water supplies or preventing the pollution of present supplies. Hundreds or even thousands of dollars have been wasted in unsuccessful attempts to procure water by drilling deep wells, and the usefulness and the safety of many city supplies have been

seriously impaired by improper location or faulty construction of wells. Two examples of useless drilling may be cited. At one place, where water was needed for the irrigation of flowers, an attempt was made to obtain a supply by drilling about 600 feet into a rock formation that furnishes large quantities of water in only a few places, and never furnishes water of the quality needed except within about 100 feet of the surface; and an attempt was made to supply water for a small city by sinking a well to a depth of nearly 2,000 feet in a locality where there was no possibility of procuring enough fresh water from a single well to supply more than two or three families, and where no water suitable for a city supply could be found more than 100 feet below the surface. Obviously a knowledge of these conditions would have effected great saving in time and money.

The problem of procuring water for industrial purposes is recognized as of great importance, particularly when a large amount of water of a certain quality or of a definite range of temperature is required. Many manufacturing plants have been located with an absolute disregard of the suitability of the available water supply, and the owners have subsequently found the cost of procuring the needed water one of their heaviest burdens. It is probable that some factories in the Blue Grass region will, in the course of a few years, be forced to pipe water from a considerable distance or move their entire plants.

In some parts of the area water for stock is obtained directly from springs and streams, and in other localities dams are built to impound surface water. Many stockmen, however, realize that stagnant water is inferior in quality, and some have already drilled wells to supply their stock; others would undoubtedly adopt the same means if they had any assurance that water of satisfactory quality could be obtained. A few have selected poor locations for the wells and have obtained inadequate supplies of water of unsatisfactory quality.

GEOLOGY.

GEOLOGIC HISTORY.

The rocks which underlie the Blue Grass region comprise formations belonging to the early periods of geologic history. The systems represented are known to geologists as Ordovician, Silurian, Devonian, Carboniferous, etc. The rocks belonging to each of these groups are further subdivided into the formations which are mentioned in the accompanying table and in the subsequent pages of the text. In the table the name of the oldest formation is placed at the bottom and the succeeding formations are arranged in regular order. This arrangement is a most satisfactory one, because when undisturbed the formations lie one upon another like the leaves of a book. However, in this case the leaves are great masses of stone in the form of

clay, sand, shale, sandstone, and limestone, sometimes nearly homogeneous, but more often mixed together or arranged in successive beds from a fraction of an inch to several feet in thickness.

All the older formations of the Blue Grass region were deposited in water, and are therefore called sedimentary rocks. A careful study of these rocks will reveal many interesting facts concerning their history. Embedded in the limestones and shales are many shells, which represent the organic life which existed in the water while the rocks were being deposited. Some of these shells appear much like those which now live in the seas, while many others may be connected with forms now living by examining the rocks of successive geologic ages and noting the gradual modifications which have taken place. The relation between the shells of organisms now living in marine waters and those found embedded in the rocks of the Blue Grass region, together with many other facts, show that the formations were deposited beneath the sea. Although it is difficult to restore the outlines of the ancient ocean in which the geologic formations of the Blue Grass region were deposited, the composition of the rocks gives much information concerning the depth and character of the waters. As most of the shells must have belonged to organisms which lived in shallow water, the depth of the sea could not have been very great. This conclusion would also be reached by a consideration of the nature of the material comprising the rocks themselves. The worn character of some shells bears testimony of such wave action as would take place only in shallow water, and the presence of sand and mud, which have since been consolidated into sandstone and shale, is evidence of shallow water and the proximity of land to supply such sediments. The great thickness of some of the limestone shows the existence of long periods when the seas were comparatively free from sediment and animal life flourished and decayed, leaving their calcareous shells to be consolidated into rock. In the Blue Grass region the earlier formations appear to have been deposited in comparatively clear waters, for the older rocks are largely limestone. The younger formations were laid down in seas which were often muddy, and hence sandstones and shales predominate.

After the deposition of the limestones, sandstones, and shales of the Blue Grass region, the rocks were raised above sea level in the form of a low dome. Probably the arching of the strata had been begun at an earlier date, but it culminated about the close of the deposition of the Carboniferous rocks. The apex of this dome lies in Jessamine County, and hence it is known as the "Jessamine dome." From the apex the rocks dip gradually outward, sinking at the rate of a few feet per mile. In places the forces which produced the doming disrupted the rocks and caused the severed ends of the beds to slip past

each other. Such breaks are known as faults, and the Kentucky River fault, which is shown in a solid line on the accompanying map, is an excellent example. Other smaller faults occur in various parts of the region. Following the doming came a long period of erosion, which reduced the surface to a low plain, known to geologists as a peneplain. Subsequent uplift permitted the dissection of the early peneplain and the formation of another at a lower level. The early peneplain is represented by the tops of the mountains which border the Blue Grass region, and the younger one by the uplands which surround Lexington. This upland, which is known as the Lexington peneplain, was formed during the portion of geologic time known as the Tertiary. The meandering streams of Tertiary time deposited broad belts of gravel, sand, and clay in their shallow valleys, and the remnants of these deposits constitute the Irvine formation. Since the deposition of the Irvine formation the Blue Grass region has been subjected to erosion, and the streams have cut deep channels, of which the Kentucky River gorge is an excellent example.

At the beginning of the Quaternary there was a great change in climatic conditions, which permitted the formation of a vast sheet of ice in northeastern North America. This ice sheet existed in the glacial period, and at the time of its maximum extent its southern border reached beyond Ohio River into Kentucky. After the ice had melted from the United States, there were other glacial invasions, which extended into northern Ohio, but did not reach as far south as Kentucky. During one of these glaciations, which is known as the Iowan, a deposit of buff-colored silt was spread over a narrow strip of land south of Ohio River from the vicinity of La Grange to Fort Thomas. This silt, which is called loess, is an important surface formation in the area mentioned.

A later glaciation, known as the Wisconsin, extended into Ohio. The waters derived from the melting of this ice sheet spread broad terraces of sand and gravel in the Ohio Valley. These terraces may be seen in the Ohio Valley, where they form broad flats above the level flood plains of the stream.

CLASSIFICATION OF ROCKS.

The name Blue Grass region has been restricted by some authors to the area in which rocks of Ordovician age occur at the surface, but the area described in this report includes also formations belonging to the Silurian, Devonian, and Carboniferous systems. The Ordovician formations, however, cover so large a part of the region that they are discussed more fully than those belonging to the other systems.

The following table shows the sequence, character, and thickness of the geologic formations found in the Blue Grass region and the amount and character of the water supply furnished by them.

TABLE 1.—*Geologic column in Blue Grass region.*

System.	Formation.	Character and thickness.	Water supply.	
			To shallow wells.	To deep drilled wells.
Quaternary.	Alluvium.	Sand and gravel along principal streams; coarse clayey gravel along small streams.	Small supplies.	Water in abundance.
	Gravels (Wisconsin).	Sand and gravel in the valleys of the streams. 80 to 120 feet thick.		Water abundant, but hard.
	Loess (Iowan).	Buff loesslike silt, but lacking characteristic texture of loess. Up to 6 feet thick.	Unimportant.	
	Till (Illinoian).	Red or yellow pebbly clay; locally of assorted sands and gravels. 5 to 300 feet thick.	Sands and gravels furnish soft water in abundance to a few wells.	
Tertiary.	Irvine.	Yellow or red clays, sands, and gravels. 3 to 12 feet thick.	Rarely water-bearing; soft water in a few localities.	
Carboniferous.	Newman limestone.	Occurs in small areas on Waverly shale. Not important in this region.		
	Waverly shale.	100 feet or more of blue shale, covered by interbedded shales and hard, even-bedded greenish sandstones. Contains concretionary iron oxide at one or more horizons. 300 feet thick.	The sandstone furnishes very pure soft water at its junction with the underlying shale. The shale furnishes no water.	Not penetrated by deep wells in the Blue Grass region.
Devonian.	Ohio shale.	Thin-bedded carbonaceous black shale. 150 feet thick.	Yields an abundance of highly mineralized water. The most common mineral waters are sulphur, chalybeate, and alum.	Not penetrated by deep wells in the Blue Grass region.

		Usually a cherty magnesian limestone with some shale beds. 30 feet thick.	Furnishes considerable water where the limestone rests on shale. The water is hard and contains magnesia.	Yields moderate quantities of magnesian water.
Silurian.	Panola.	Blue shales and yellow limestones, in places containing chert. Locally includes some sandstone. Varies greatly in thickness, with a maximum of 60 feet. Includes sediments of Niagaran and Onondaga age.	The limestones furnish good supplies of hard water containing magnesia. The shales supply some mineral water for springs and shallow wells.	The limestones furnish considerable water in some localities.
Ordovician.	Richmond.	Heavy-bedded arenaceous limestones, gray or blue, weathering to buff; about 10 feet of dense calcareous shale in the lower part. Locally an impure sandstone. 60 feet thick.	Furnishes an abundance of water in the limestone areas and where the sandstone is not too shaly. Water usually contains considerable magnesia.	Seldom penetrated by wells. The sandy phase may furnish some water.
		Blue or dove-colored nodular limestones and blue shale, the shale beds predominating. 125 feet thick.	Furnishes moderate quantities of hard water.	Seldom furnishes satisfactory supplies.
		Interbedded blue limestone and shale. Shale predominates in northern part of the region, but heavy beds of limestone occur farther south. 80 feet thick.	Where heavy beds of limestone are at the surface, good supplies of hard water are obtained from springs and shallow wells.	The limestone beds furnish considerable water where within 100 feet of the surface. Deep wells may encounter brackish water containing hydrogen sulphide. The best supplies are obtained where the limestone layers are near the surface.
	Maysville.	Interbedded blue limestones and shales, the alternate layers usually thin and nodular. In general the shales predominate, and the limestone layers are in places thin and shaly. Some moderately heavy beds of limestone occur at certain horizons, but the usual thickness of single beds is less than 1 foot. 230 feet thick.	This formation yields moderate quantities of hard water. Water conditions are most favorable where the formation contains most limestone at or near the surface. Contains many springs of moderate size, and shallow wells are commonly successful.	Seldom yields water at depths greater than 150 feet. The best supplies of hard water are commonly obtained within 50 feet of the surface, though in some localities good supplies are obtained at a depth of 100 feet or slightly more. Water encountered below the level of the surface streams is apt to be brackish and to contain hydrogen sulphide.

TABLE 1.—*Geologic column in Blue Grass region*—Continued.

System.	Formation.	Character and thickness.	Water supply.	
			To shallow wells.	To deep drilled wells.
Ordovician.	Eden shale.	In southern part of region upper beds are of shaly sandstones, in some places concretionary, called the Garrard sandstone member; lower part is same as the Eden farther north. In northern part of region the formation consists of blue shales, containing some sandy layers and local beds of limestone. Maximum thickness of the Garrard sandstone member is about 150 feet, and it gradually thins northward. 200+ feet thick.	The sandstone supplies moderate quantities of water in some localities. The shale supplies small quantities of water.	Seldom water-bearing. Deep wells are unsuccessful.
	Winchester limestone.	Blue and gray limestones with some blue shales. Limestone layers commonly rough and in some places having waved upper surface. 60+ feet thick.	Moderate quantities of hard water.	Usually furnishes no fresh water, but may supply strong brines, which often contain hydrogen sulphide.
	Lexington limestone.	Gray crystalline limestone, usually lighter colored and more cherty than the underlying limestone. (Flanagan chert member.) 75 feet thick.	Yields an abundance of hard water for springs and wells. Contains many large underground streams and supplies large springs.	Many good wells. When penetrated below the level of surface drainage the supplies are saline and saline-sulphur.
		Lower 10–35 feet consisting of light-drab argillaceous limestone with shale beds, overlain by 100 feet of gray or blue thin-bedded nodular limestone, separated by thin partings of shale; at the top 20–60 feet of subcrystalline, gray, siliceous sand and locally phosphatic limestone. 194 feet thick.	Supplies an abundance of hard water for springs and wells.	Below the levels of surface drainage supplies mineral waters—usually salt or salt-sulphur.
		Heavy-bedded coarse-grained crystalline cherty limestone; usually gray. 30 feet thick.	Yields considerable hard water.	Will supply no fresh water when found below level of surface streams. May yield salt-sulphur water.

41	New Haven	Highwood	Marcus Wooding	Slope	Large.		Constant		Sandstone	Sale	Cherry Hill Spring; dug to a depth of 3 feet.
42	do		W. S. Swayne	Base of hill			do		Rock	do	Clear water.
43	do		City	River bank	4				Sand	Drinking	Cold Spring.
44	New Milford	Gaylordsville	H. H. Pomeroy	Near top of hill	(*d*)		Slight		do	Stock	
45	do	do	E. H. Austin	Valley	(*d*)	45–56	do	Hard		Domestic	
46	do	Northville	Starr Kinney	Hillside	30	42	Constant	Soft		Domestic, cooling.	
47	do		Leroy Randall	do	Large.		do			Drinking	
48	do		Bridgeport Wood Finishing Co.	do	(*d*)		Little variation.	Soft	Schist	do	Indian Rock Spring.
49	Newtown	Sandy Hook	Leroy Mitchell	do	15			Soft, iron	Rock	Domestic	
50	North Canaan	Canaan	J. S. Adams					Hard	Limestone		Numerous springs in vicinity, from limestone.
51	do	East Canaan	W. T. Owens								Numerous springs of excessively hard water in this locality.
52	do	do	R. C. Geer	Hillside			Constant	Medium hard.	Gravel	Domestic, stock.	
53	do		W. H. Camp	do	(*e*)			Hard	Limestone	General	
54	North Franklin.		L. A. Robinson	do	(*f*)		Constant	Soft		Domestic	
55	North Haven	Montowese	B. F. Judd	Elevated ground.	5		Less in dry weather.	do	Trap rock	Table, medicinal.	Hermitage Spring. See analysis, p. 179.
56	North Stonington.		Thos. B. Hewitt	Valley		50	Constant	do			
57	Norwalk	West Norwalk	Mrs. M. C. Hite	Hillside	7		do	do	Crystalline rock.	Domestic	Collected in a small reservoir pond.
58	Norwich		Carpenter & Williams.	do			do	do	Sand	Drinking	Puritan Spring; housed in.
59	Old Lyme	Lyme	Louis P. Dessar	do	2½		do	Soft, iron	Granite	Domestic	Deposits an iron sediment.
60	do	do	Chas. T. Ely	Slope	3	52	do	Soft	Sand	Drinking	From sand beneath hardpan.
61	do	South Lyme	Hatchells Improvement Co.	Hillside			do			Domestic	Supplies 5 families.
62	Old Mystic	Mystic	Edwin Lamphere	Flat			do	Chalybeate		Medicinal	Surrounded by a heavy iron deposit.
63	Oxford		S. P. Sanford					Iron, sulphur.	Rock	do	Deposits of iron from water. See analysis, p. 179.
64	Pomfret	Abington	Willis Covell	Hillside	Large.		Constant	Soft	Soil	Drinking	
65	do		A. B. Lapsley	do	1		do	do	Clay	Domestic	See analysis, p. 179.
66	Ridgefield		Chas. Holly	Hill	(*g*)	48	do	do	Crystalline rock.	Sale	Mamanasco Spring. See analysis, p. 179.
67	do		B. A. Bryon	Hillside	5	40		do	do	do	
68	Seymour		T. F. Gilyard	do	1		Constant	do	Schist	Domestic	
*69	do		R. T. French	Base of hill	5	47		do	Sand	Sale	Arethusa Spring. See analysis, p. 179.
70	Sharon	Ellsworth	S. E. Everett	Hillside	1			do	Crystalline rock.	Drinking	
71	Sherman	Brookfield	C. I. Leach	do		50	Constant	do		Domestic	
72	Simsbury		N. W. Dodge	Valley	1	44			Soil	do	Seeps out.

a 1½-inch pipe.
b 1,000 gallons per day.
c ½-inch pipe.
d 1-inch pipe.
e 4-inch pipe.
f ¾-inch pipe.
g 2-inch pipe.

Records of springs in Connecticut—Continued.

No.	Town.	Locality.	Owner or authority.	Location.	Yield per minute.	Temperature.	Variation in flow.	Quality.	Source reported.	Use.	Remarks.
					Gallons.	° *F.*					
73	Southbury		W. Lockwood and N. W. Mitchell.	Base of hill	(*a*)		Less in dry weather.	Soft	Gravel	Drinking	
74	Stafford Springs.		Stafford Springs Mineral Water Co.	do		52	Constant	Soft, iron	do	Hotel, sale.	Used for medicinal purposes.
75	Stonington	Mystic	B. F. Williams	Hillside			do	Soft	Rock	Domestic	
76	Stratford	Oronoque	D. S. Guthrie	do			Less in dry weather.	do	Sand	do	
77	Suffield		E. C. Holdridge	do	1½	45	Constant	do	Gravel	do	
78	Tolland	South Willington.	Mrs. E. J. Holman	do	1	50	do	do	Crystalline rock.	do	
79	Torrington		W. T. Church	do	(*a*)		Nearly constant.	do	Schist	Sale	Mica Spring.
80	do		Coe Brass Co	Base of hill	(*a*)	50			Rock	Drinking	
81	Vernon	Rockville	Edgar Keeney	Base of bluff	Small.		Little variation	Soft	Crystalline rock.	Domestic	Supplies 3 families.
82	Warren	New Preston	Geo. C. Hopkins	Hillside	(*b*)		Less in dry weather.	do	Hardpan	do	
83	Westport	Southport	John H. Jennings	Base of hill	Good.	50	Constant	do		Sale	Port Royal Spring. See analysis, p. 179.
84	Wilton		Edward Olmstead	Hillside			Varies		Crystalline rock.	Domestic	
85	Winchester	Winsted	R. E. Holmes	Base of hill	(*c*)	50	Increases with heavy rain.	Soft	do	Stock	
86	Windham	North Windham.	E. H. Hall	Hillside	10		Constant	do	Sand, gravel	Domestic	
87	Windsor		W. H. Harvey		2			do	Sand	do	
88	do		E. E. Case	Valley	3			do	do		
89	do		Windsor Water Co.	Hill slopes			Decreases 33 per cent in dry weather.	do	do	City supply.	
*90	Windsor Locks		Windsor Locks Water Co.	do				do	do	do	Reservoir fed by seepage springs from sand. See analysis, p. 179.

a 2-inch pipe. *b* 1¼-inch pipe. *c* ½-inch pipe.

NOTES.

8. Located at the northern edge of Whortleberry Hill, a ridge of gneiss overlain by sandy till. It is situated in a large seepage area from which flows probably twice as much as issues from the spring. Although rock outcrops are near at hand, it is probable that the water comes from the till and is part of an underflow draining the ridge to the south. Water rises 6 inches above entering point.

69. Inclosed by four sections of 3½-foot tiling sunk into the ground. Water comes from the fine white sand probably resting on a ledge of gneissoid granite. The yield to the bottling works is 5 gallons a minute, and the overflow is probably 10 gallons a minute, giving a total yield of about 15 gallons. The spring is located on a rather flat terrace at an elevation above the river of about 120 feet.

On the hillside, 200 yards away from the Arethusa Spring and at an elevation about 25 or 30 feet higher, another spring issues from light-colored gneissoid granite, with the structure planes dipping about 4° SE. into the hillside. Both these springs maintain nearly the same flow throughout the year.

90. The water supply is obtained from three ponded areas located in a shallow valley and fed by springs. The topography is flat and the soil is porous. The run-off is accordingly small and the soil absorption large. The ground water is near the surface and emerges on a nearly level area at the contact of till and the thin overlying deposit of sand.

The following notes cover a few springs that are not listed in the table:

Granite Rock Spring, Higganum: This spring issues between two large granite bowlders on the upper slope of a high hill, but no rock outcrops are visible. The water is piped to a bottling works. The spring yields between 20,000 and 25,000 gallons a day, with a fairly constant flow, at a temperature of 49° F. when the air temperature is 77°. The output of the bottling works during 1905 was about 50,000 gallons. A second spring, recently excavated, is said to issue from a crevice one-eighth inch wide in the ledge.

Ausantowea Spring, Woodmont: Has been excavated to a depth of 20 feet through hardpan, sand, and gravel, the water horizon being in gravel. Flows 100 gallons an hour and varies little in yield with seasons. The temperature is 57° when the air temperature is 88°. The water is bottled and sold.

Buttress Dike Spring, Woodbridge: This "spring" is in reality a flowing well in which water rises 18 inches above the ground. It is on the side of a steep hill composed of chlorite schist and overlain by a thin layer of sandy till containing numerous heavy bowlders. The water appears to come from a vertical cleavage joint in the rock.

Springs of T. T. Wilcox, two-fifths of a mile southeast of Highland station: Three springs, two of which are reported by Mr. Wilcox to furnish 51 barrels a day, with no seasonal variation, at a temperature of 48° to 50° F. The only contributing area at a higher level than the spring is a hill with an elevation of less than 40 feet and covered with a thin layer of till. The water apparently reaches the surface by working along the bedding planes between sandstone and red shale. This requires a movement up a slope of about 15°.

Spring of Charles Parker, 1 mile southeast of Meriden: This spring is located on the west side of a hill composed of sandstone dipping southeast and capped with a thin covering of glacial drift. The water comes from joints in sandstone, as illustrated on page 136. The temperature of the water is 51° F. when the air temperature is 56°.

Chalybeate Spring, Litchfield: This interesting spring, which was famous in the early days of Connecticut, was described as follows by James Pierce:[a] "It issues from an extensive bed of sulphuret of iron, situated on the eastern side of Mount Prospect, 4 miles west of the village of Litchfield. The spring is copious and perennial, exhibiting in its course much oxide of iron and a white deposit."

[a] Am. Jour. Sci., vol. 3, 1821, p. 235.

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	Dense fine-grained gray or light-drab limestone, 90 feet thick, near the base; covered by several feet of soft fine-grained limestone containing calcite crystals and some pyrite. The upper 20 to 40 feet dove-colored fine-grained limestones, containing many calcite crystals and separated by layers of shale a few inches to 4 feet thick. The top layer usually a light-gray crystalline limestone. Near the top a bed of soft unctuous green clay.	Considerable hard water for springs and shallow wells.	Yields considerable salt and salt-sulphur water.
Highbridge limestone.	Dense fine-grained limestones, arranged in heavy even beds; light dove-colored to gray. Dolomitic at the top and bottom and containing many seams of dolomite through the entire series. 20 to 30 feet thick.	Some hard water for springs and shallow wells.	Not distinguished from the other Stones River formations. Will yield nothing but salt or salt-sulphur water.
	Dense fine-grained massive limestone, in places partly crystallized. Usually dark drab or dove-colored. Heavy bedded, but with some shaly partings. 285 feet thick.	Yields considerable hard water for springs and shallow wells in Kentucky River gorge. Contains some caverns.	Yields salt or salt-sulphur waters only.
	Known only from well records. Limestone resembling the overlying beds; rarely shale. 100+ feet thick.		Yields nothing but salt or salt-sulphur waters.
St. Peter sandstone.	A siliceous limestone, not exposed and known only from well records. Occurs at horizon of St. Peter sandstone.		Yields strong salt-sulphur water under sufficient head to rise 580 to 600 feet above sea level. Furnishes flowing wells in the valleys of Ohio, Licking, and Kentucky rivers.

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ORDOVICIAN SYSTEM.

ST. PETER SANDSTONE.

At a depth of 100 feet or more below the oldest rocks seen at the surface in Kentucky, the dark, fine-grained limestones of the surface formation are underlain by a greenish or white sandstone or sandy limestone, the transition, as indicated by the well records, being abrupt. This underlying formation has been called Calciferous by the Kentucky geologists, but it is correlated and usually identified with the St. Peter sandstone of the Mississippi Valley by most geologists working north of Ohio River. Well records indicate that beneath the Blue Grass region the St. Peter is composed largely of fine-grained siliceous limestone, whose thickness has not been determined in Kentucky, but wells that have been drilled to a depth of 500 to 700 feet below its top show no marked change in the character of the rock.

HIGHBRIDGE LIMESTONE.

The fine-grained limestone exposed in the Kentucky River gorge in the Richmond quadrangle was named by Campbell[a] the Highbridge, and Miller[b] subsequently included under this name all the rocks exposed in Kentucky lying below the top of Campbell's Highbridge limestone. As thus defined, the Highbridge comprises 400 feet of massive drab or dove-colored fine-grained limestone, in some places so even grained that it resembles lithographic stone. As a rule, however, it contains crystals of calcite, and near the top some of the layers are largely crystalline. About 100 feet beneath the top it is divided into two readily distinguishable parts by dolomitic layers. The lower limestone is nearly always heavy bedded, but the most of the layers of the upper limestone are thin and interbedded with shale beds ranging in thickness from 1 inch to 4 feet.

The great thickness of the Highbridge limestone appears to indicate deposition in comparatively clear water, but toward the close of this period of deposition land-derived sediments predominated at frequent intervals, during which the thin shale beds of the upper limestone were formed.

The Highbridge limestone is exposed in the Kentucky River gorge from below Frankfort to a short distance above Camp Nelson, and some isolated exposures are found in Madison, Clark, and Fayette counties, where the Kentucky River fault brings the upper division of the Highbridge to the surface. The formation is also exposed in the valleys of some of the tributaries of Kentucky River. Thus it extends along Dix River to a short distance south of the line between Boyle and Lincoln counties; along Clear Creek in Jessamine County,

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

[b] Miller, Arthur M., The lead and zinc bearing rocks of central Kentucky: Bull. Kentucky Geol. Survey No. 2, 1905, pp. 10–16.

south of Troy; along Jessamine Creek to a point within 5 miles of Nicholasville; along Hickman Creek to a point just north of Union Mills; along Boone Creek to a point just east of Athens. On the smaller tributaries the Highbridge limestone seldom extends more than 5 miles from the river. It does not appear on the upland except in the southern part of Jessamine County.

LEXINGTON LIMESTONE.

As originally defined by Campbell,[a] the Lexington limestone included 140 to 160 feet of strata resting on the Highbridge limestone and covered by 50 feet of cherty limestone, which was mapped as the Flanagan chert. More extensive stratigraphic and paleontologic work led Miller[b] to include the Flanagan chert with the Lexington limestone. Under this definition the formation consists of 200 feet or more of coarse-grained blue or gray limestones, in some places containing shaly partings and thin beds of bluish shale. The limestones are in part thick bedded and in part thin bedded and nodular. At various localities nodules and lenses of chert occur in the upper 50 to 75 feet of the formation.

The Lexington limestone represents deposition in comparatively clear water, but with occasional sediments, which gave rise to the shale beds. Plate II, *B*, shows a section of the formation.

The formation is found over a large area in the region surrounding Lexington, and it is generally considered the basis of the finest bluegrass soils. The northern line of the Lexington limestone passes across Harrison, Bourbon, Scott, and Franklin counties; the western line lies a few miles west of Kentucky River from Franklin County to Boyle County; the southern line crosses northern Garrard and Madison counties; and the eastern line extends through Clark and Bourbon counties. In a part of this central area it is covered by the next younger formation, the Winchester limestone. Small exposures of Lexington limestone are also seen at various points along Ohio River from above Belmont to below Moscow, but in this region the formation does not lie high enough above the stream to reach the level of the upland. The upper beds of the Lexington limestone are important water-bearing strata.

WINCHESTER LIMESTONE.

The name Winchester is applied in this report to the series of interbedded blue limestones and shales resting on the Lexington limestone. As described by Campbell in the Richmond folio, the Winchester limestone included 200 to 230 feet of blue shales and limestones,

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

[b] Miller, Arthur M., The lead and zinc bearing rocks of central Kentucky: Bull. Kentucky Geol. Survey No. 2, 1905, pp. 16–22.

extending from the top of the Flanagan chert to the base of his Garrard sandstone. The Winchester of Miller's report on the lead and zinc bearing rocks of central Kentucky represents the lower 40 feet of the rocks which Campbell called Winchester. Later work indicates that the use of the term Winchester to include the entire series of limestones and shales between the Lexington limestone and Campbell's Garrard sandstone is open to objection. At least the lower part and possibly the whole of Campbell's Garrard sandstone is to be correlated with the upper portion of the Eden shale at Cincinnati. Indeed, when traced northward the lower part of this sandstone gradually gives place to the Eden shale. Although the upper boundary of this sandstone, as developed on the eastern side of the Cincinnati arch, appears to fall within the beds usually classed with the lower division of the Maysville, it is thought advisable to adopt the classification which makes the Garrard sandstone a member of the Eden shale and restricts the name Winchester to the shaly limestone of late Trenton age which underlies the Eden shale.

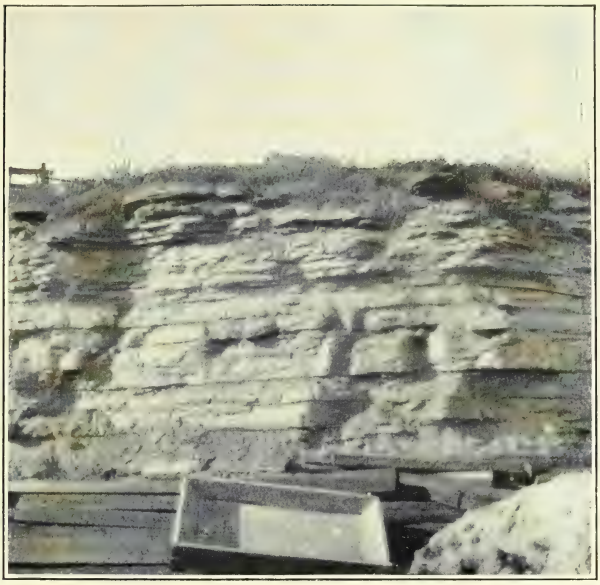
The rocks of the Winchester limestone are much like those of the Lexington, except that the proportion of shale is larger. (See Pl. II, *A*.) At several localities the top of the formation is marked by the base of a current-formed bed of limestone, 18 inches or more in thickness, which shows marked cross lamination and contains fragments of the underlying rock. Many bits of crinoid stems in the layer have led to its being called the "crinoidal layer." In the valley of Licking River this layer appears to rest on the Winchester, but, according to Mr. Ulrich, opposite Cincinnati it rests on the lower part of the Lexington. Thus there appears to be a marked unconformity above the Winchester. The maximum thickness of the Winchester limestone is probably somewhat greater than the thickness given by Miller.

The Winchester appears to represent a period during which frequent alternations of clear and muddy water gave rise to a series of interbedded limestones and shales. The numerous shale beds make the Winchester a rather poor water-bearing formation, but where it is at the surface it usually yields enough water for domestic and farm uses.

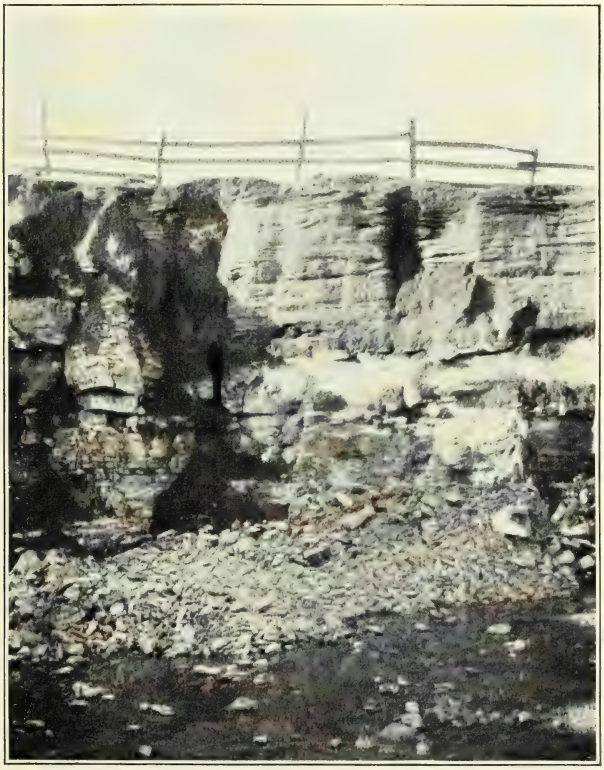
The Winchester is exposed along Ohio River on the eastern and western sides of the Blue Grass region. A narrow band of it surrounds the central area of Lexington limestone, and large exposures of it are found within that area.

EDEN SHALE.

The rocks of this formation, where typically developed, comprise about 250 feet of blue shale containing thin scattered beds of blue limestone. In the valley of Ohio River at Cincinnati the Eden



A. WINCHESTER LIMESTONE, WINCHESTER, KY.



B. LEXINGTON LIMESTONE, PARIS, KY.

shale is locally separated from the underlying Lexington limestone by a few feet of gray shale containing characteristic Utica fossils. Near the southern border of the Blue Grass region the upper part of the formation is composed of the sandy shale and sandstone which, as already stated, were called by Campbell [a] the Garrard sandstone and are here called Garrard sandstone member, following the later definition which makes them a part of the Eden shale. The thickness of the Garrard sandstone member is variable, the maximum being about 150 feet. The thickness of the Eden shale where it includes the Garrard sandstone member also varies, but it is in no place more than 300 feet. Some of the limestone layers of the Eden have a wavy upper surface, which appears to be due to ripple marks formed during the deposition of the rock.

At the beginning of the deposition of the Eden shale a large amount of land-derived sediment appears to have been carried into the Ordovician sea. Evidence as to the source of the land-derived sediments forming the earlier beds is lacking, but the character of the Garrard sandstone member suggests that during the deposition of the upper part of the Eden shale considerable coarse sediment was being supplied from some land area to the south. The deposition of this coarse material continued throughout a large part of the period and into the earlier part of the Maysville.

The Eden shale is exposed along Ohio River and its principal tributaries and forms a rim from 15 to 30 miles wide around the central area of Lexington and Winchester limestones. The boundary between the Eden and the Maysville is difficult to map accurately because the Eden shale usually appears in the stream valleys within the areas of Maysville, and the Maysville at many places caps the hills of Eden shale some distance beyond the generalized boundary.

MAYSVILLE FORMATION.

The Maysville formation comprises a series of interbedded blue limestones and shales more than 200 feet thick. Few of the beds of limestone exceed 4 to 6 inches in thickness, and toward the top of the formation many of the beds are sandy. Evidence indicates that the Maysville formation is separable into several subdivisions, but the lithologic variations are as a rule so gradual that the writer found it impracticable to draw satisfactory lines in the time at his disposal. In general the proportion of shale beds is high in the lower and middle parts of the formation, but below the middle and near the top some heavy beds of limestone occur that are sufficiently thick to permit the formation of small caverns.

The transition from the conditions which existed during the deposition of the Eden shale appears to have been gradual, so that the

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

lower portion of the Maysville consists of shale in the northern part of the area and sandstone in the southern part. The limestone beds of the Maysville were deposited during short periods when the sea was comparatively clear.

The Maysville formation is exposed over a large area in the Blue Grass region. It forms a rim about the central area of the Lexington limestone, reaching Ohio River on the north and extending nearly to the mountains on the south.

RICHMOND FORMATION.

The Richmond formation is probably separable into at least three members, but in this report only two subdivisions are recognized. The lower part of the formation consists of blue or dove-colored even-bedded limestone, containing much interbedded shale. Commonly the shale is the predominating rock, and in some places, especially on the east side of the Jessamine dome, the rock appears to be almost entirely composed of sandy shale. The upper division of the Richmond consists of greenish to buff sandy limestones or calcareous sandstones, with some beds of shale. Near Ohio River the upper beds are largely limestone, but toward the south they give place to arenaceous limestones and sandstones which show a marked banding on exposure to the weather. Apparently some of the rocks classified as Medina by the early surveys of Kentucky belong to the upper division of the Richmond. Exposures of the limestone of the Richmond formation are to be seen in the vicinity of Milton, and they extend southward beyond the southern line of Oldham County.

The Richmond was observed at various points on the east and west sides of the Cincinnati arch. It forms a band of varying width about the south and west sides of the Maysville area, and it is well developed outside the Maysville areas on the east side of the Cincinnati arch.

SILURIAN-DEVONIAN ROCKS.

PANOLA FORMATION.

The rocks of Silurian and Devonian age in the area under discussion are sufficiently distinct to admit of separation into at least four formations, but with the exception of the Ohio shale, their thickness and areal extent are insufficient to permit their discrimination on a map of the scale here employed. For this reason the name Panola formation, which was proposed by Campbell, is used for the Silurian and Devonian rocks lying between the top of the Richmond formation and the base of the Ohio shale.

The Panola formation includes representatives of Niagaran and Onondaga age. The basal beds of Niagaran age consist of a heavy-bedded yellow limestone followed by interbedded limestone and blue

shale. At some localities these beds contain low-grade iron ore. Niagaran time appears to be represented on the eastern side of the Cincinnati arch by 10 to 20 feet of blue shale containing more or less intercalated yellow limestone, but the corresponding formation on the west side consists mainly of several feet of heavy magnesian limestone which in places contains a little chert.

The strata of Onondaga age consist of 15 feet of buff magnesian limestone, with some thin beds of shale near the base. Some of the layers of this limestone contain numerous nodules of chert, and locally it is crowded with fossil corals.

The variations in the thickness and character of the members of the Panola formation—the many alternations from limestone to shale—suggest frequent changes in the conditions of deposition, especially those of the Niagaran strata. Some of the differences in thickness may be due to irregularities in the rate of deposition, but others are probably to be accounted for by supposing that an unconformity exists between the Silurian and Devonian. No detailed study was, however, made of outlying parts of the area, where these rocks are exposed.

DEVONIAN SYSTEM.

OHIO SHALE.

This formation consists of a thinly laminated, black, carbonaceous shale, which reaches a maximum thickness of about 150 feet in Fleming County and thins westward toward the west edge of Boyle County, where it passes outside the Blue Grass area. In the eastern part of the region few of the exposures exceed a few miles in width and in Boyle County the width is less than a mile. The formation is the equivalent of the Chattanooga shale farther south.

The relation of the Ohio shale to the underlying Devonian limestone was seen at several points. In some places the transition from the limestone to the shale is abrupt; in others it is by interbedding of the limestone and shale. The Ohio shale appears to have been deposited during a period when the sea was gradually encroaching upon the land. The fine sediments and the plant remains of this formation suggest that the sea was shallow and the adjacent land low.

CARBONIFEROUS SYSTEM.

WAVERLY SHALE.

The Waverly shale, which has a maximum thickness of 300 feet, includes about 100 feet of dense blue shale, which passes upward into interbedded shale and sandstone. Near the base of the shale are numerous concretions of iron carbonate which weather to a reddish brown. In most places the sandstones have a greenish or

bluish tinge and they are commonly even bedded, but in some localities they are decidedly concretionary. Some beds of limestone occur on the tops of the mountains, but the areas are so small that they are not shown in the geologic map of the region

TERTIARY SYSTEM.

IRVINE FORMATION.

The valleys of the principal streams in the Blue Grass region present certain peculiarities which are worthy of note. All the large streams flow in steep-walled canyons, many of which have been cut 300 to 400 feet below the level of the uplands. Bordering the canyon valleys are broad rock shelves which are but little lower than the surrounding uplands and which were formed at a time when the streams flowing across the surface of the upland had so little fall that they meandered widely. These streams left along the rock shelves deposits of yellow and gray unconsolidated sand, gravel, and clay, which were called by Campbell [a] the Irvine formation and were referred tentatively to the Neocene. That the materials in these deposits were derived in part from the formations near the headwaters of the streams is shown by the occurrence of pebbles from those formations.

The Irvine formation occurs in isolated patches along Licking River in Fleming, Nicholas, Robertson, Harrison, Pendleton, Grant, and Campbell counties. Along Kentucky River the deposits were noted in Madison, Jessamine, Woodford, and Franklin counties, and they doubtless occur in the other counties bordering the river above Franklin County. They were not observed below the western boundary of Franklin County, although they probably occur there.

QUATERNARY SYSTEM.

GLACIAL DEPOSITS.

The deposits of glacial age in the Blue Grass region include the unassorted bowlder clay, the loess, and the assorted glaciofluvial gravels that form the terraces in the Ohio Valley.

Bowlder clay.—On the upland the bowlder clay is composed of 3 to 10 feet of red or yellow clay containing fragments of limestone, chert, and granitic rocks. The clay appears to be reworked residual material, and the limestone and chert are largely of local origin, but the granitic rocks are rare and must have been brought from beyond the northern boundary of the United States.

The eastern boundary of the bowlder-clay deposit extends northward from the southern line of Oldham County to the east bluff of Ohio River at Carrollton, passing a few miles east of La Grange and

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

Bedford. From Carrollton it extends northward, passing near Richwood, Boone County, and Buffington, Kenton County, and finally terminating at Ohio River near Fort Thomas. From Fort Thomas southward the boundary coincides very closely with the Ohio Valley to Augusta, at which point it swings eastward into Ohio. This boundary marks the farthest extent of the Illinoian ice sheet.

In the Ohio Valley, as shown by Leverett,[a] are deposits of partly assorted till which in some places rise to a considerable height above the river. The most conspicuous of these deposits are the glacial conglomerate at Split Rock, near Bellevue, Boone County, and a similar conglomerate at Augusta, in Bracken County. At Split Rock the conglomerate rises 250 to 300 feet above the Ohio, but at Augusta its height is only about 175 feet. Leverett mentions also that a morainic deposit on the east edge of the Ohio Valley at Carrollton occupies a sag in the hills between Kentucky and Ohio rivers and has a width of less than a mile, and a height of 200± feet above Ohio River.

The bowlder clay is correlated with the Illinoian drift farther west. Between the period of its deposition and the next glacial invasion there was a long interval known as the Sangamon interglacial epoch, during which the Illinoian drift deposits were probably more or less modified by erosion and weathering, but it is difficult to obtain evidence of these changes, because exposures are rare.

Loess.—The material classified as loess consists of 2 to 4 feet of buff loam, which rests on the till of the upland. As a rule, it contains more clay than typical loess and it lacks the loess texture. It closely resembles the residual clay of the region and can hardly be distinguished from the clay except where it rests on the till. The loess has usually been considered a deposit formed during the closing stage of the Iowan glaciation.

The deposition of the loess appears not to have been followed by any extensive topographic changes in the Blue Grass region. Some erosion has doubtless taken place, but the most noticeable change on the loess-covered area is seen in the numerous small sink holes where the glacial deposits are underlain by limestone beds.

Glacial gravel.—Glacial gravel forms terraces along Ohio River on the border of the Blue Grass region. It consists of 80 to 120± feet of coarse sand and gravel deposited from the waters supplied by the melting of the Wisconsin ice sheet. The materials composing this deposit are sand containing pebbles of limestone, sandstone, and the various granitic rocks which were carried by the glacier.

A deposit of sand and gravel, which ranges from 10 to 80 feet in thickness and which appears to be in part glacial and in part post-

[a] Leverett, Frank, Glacial formations and drainage features of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 25–58.

glacial, is found along all the large streams of the region. Along Kentucky and Licking rivers fragments of terraces which rise to about the altitude of the glacial terraces are seen at many places. These deposits were probably made at the time when the terraces were being formed in the Ohio Valley.

Three well-defined terraces are recognizable at various points along Ohio River, but as in all of them the material is of fairly uniform character, the terraces have no effect upon the water capacity of the deposits. However, the depth to water in the glacial gravels is naturally greatest upon the highest terrace. A difference in the quality of the water has been reported in some localities, but on careful study it appeared that the variations in quality were due to the distance from the river and had no relation to the heights of the terraces.

ALLUVIUM.

On Ohio, Kentucky, and Licking rivers below the level of the glacial terraces are deposits of sand and gravel which are of recent origin. These deposits are nowhere extensive, and they exceed 50 feet in thickness at but few places.

Where the streams from the upland emerge in the valleys of the rivers they usually build alluvial fans, consisting of fragments of the country rock mixed with sand and clay. These alluvial fans are largest along Ohio River, but they also occur along the other large streams.

Many of the small streams of the region are bordered by narrow belts of coarse alluvium, which consist largely of partly rounded fragments of limestone mixed with more or less clay.

GEOLOGIC STRUCTURE.

JESSAMINE DOME.

The rocks of the Ohio Basin are not extensively folded and most of them dip slightly toward the northwest. The most important structural feature of the region is the broad arch, commonly known as the Cincinnati anticline. This arch extends from Nashville northeastward through Lexington nearly to Cincinnati, north of which it divides, one branch continuing northward, the other turning toward the northwest. South of Cincinnati the arch is separable into two broad domes; one of these culminates near Nashville, Tenn.; the apex of the other is in Jessamine County in central Kentucky. The Jessamine dome, as it has been called, has been so completely beveled by erosion that its dome structure has no apparent effect upon the surface, which is a broad plain deeply trenched by some of the larger streams. The erosion of this dome has exposed the Ordovician rocks which underlie the Blue Grass region. Outward from the apex of the dome the formations are successively younger, except where the

regular order of the succession is broken by faults which have brought younger formations into abnormal contact with the older.

From the apex of the Jessamine dome the rocks dip gently outward in all directions, but the dip varies greatly in different directions, indicating that the dome is not symmetrical, and on the southern side the regularity of the dip is broken by faulting. From the apex of the dome along the crest of the uplift to Belmont, on Ohio River, the dip does not exceed 5 or 6 feet per mile; toward the north it is only 8 or 10 feet per mile; but the dips toward the east and west are much greater; the dips toward the northeast and northwest are about 25 to 30 feet, and toward the east and west nearly 50 feet per mile. The dips toward the south can not be satisfactorily determined because of the faulting, which has produced considerable displacement of the beds.

FAULTS.

The greater number of the faults of the Blue Grass region are strike faults; that is, the fault planes are parallel to the strike of the rocks. The most conspicuous fault is the Kentucky River fault, which extends from Clark County to Garrard County. It has a maximum throw of about 400 feet, which brings the Highbridge limestone into contact with the Garrard sandstone member of the Eden shale. Where this fault was observed, the movement appears to have been along a series of parallel planes, and at its eastern end near Ruckerville, as pointed out by Campbell,[a] the fault is represented by a slight fold. Another fault extends from Kentucky River northeastward near Ruckerville and into Bath County. The maximum movement along this fault plane is about 300 feet. Other faults are known to occur in Garrard and Madison counties, but in few of these is the displacement large.

Near Moberly there is a fault which runs parallel to the direction of dip—a dip fault.[a] The amount of displacement at this place is sufficient to bring the Ohio shale into contact with the Ordovician formations.

A strip of Eden shale extends from eastern Jessamine County northeastward across Fayette County. This strip of shale, which is from one-eighth to one-fourth mile wide, represents a place where two parallel faults have brought the Eden shale down into the area of Lexington limestone.[b] In northeastern Franklin County are two faults, which extend a considerable distance across the line into Scott County.[b] These two faults inclose a small fault block similar in origin to the one near Lexington. Other faults are known to occur in various parts of the region.

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[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

[b] Miller, A. M., The lead and zinc bearing rocks of central Kentucky: Bull. Kentucky Geol. Survey No. 2, 1905, p. 7.

The geologic history of the Cincinnati arch has been long and complex, but a comprehensive discussion is beyond the scope of this paper. In general, it may be inferred that there were periods of partial emergence from beneath the sea, followed by more or less complete resubmergence. There is reason to believe that the faulting dates from the final emergence, which probably occurred during Carboniferous time. This question has been fully discussed by Miller in Bulletin 5 of the Kentucky Survey.

JOINTS AND BEDDING PLANES.

In the Blue Grass region there are two well-developed series of vertical joints at approximately right angles to each other. These joints have general north-south and east-west directions and are apparently very persistent. The spacing of the joints is somewhat irregular, and consequently it is difficult to state what interval there may be between joints at any given point.

Besides the joints, there are between the layers of rock numerous horizontal planes of separation known as "bedding planes." The spacing of the bedding planes varies from a fraction of an inch in the Eden shale to several feet in parts of the Highbridge limestone. The variation depends entirely on the thickness of the beds of rock, and consequently the number of bedding planes is greater in the shales than in the limestones.

In limestones and shales the joints and bedding planes have an important relation to the occurrence of underground water.

In rocks freshly exposed bedding planes and joints are usually but a small fraction of an inch in width; but near the surface the joints are wider, especially in the limestones, where they may be represented by caverns several feet wide. Within a few feet of the surface these openings are commonly filled with residual clay, and it is by the gradual removal of the limestone and the consequent enlargement of the cavern that the numerous sink holes of the region are formed. The enlargement, for obvious reasons, is most common along the lines where joints and bedding planes meet.

PHYSIOGRAPHY.

ALTITUDE OF THE SURFACE.

Altitudes within the Blue Grass region have an extreme range of about 1,100 feet, and the transition from one level to another is usually abrupt. The general altitude is between 800 and 1,000 feet above sea level. The higher points of the area, underlain by Ordovician rocks, rise to a nearly uniform altitude of 1,000 feet above sea level, while the lowest point, less than 400 feet above sea, is on Ohio

River at the southwest corner of Oldham County. On the southern margin of the area the hills of Mississippian rocks rise to an altitude of nearly 1,500 feet above sea level.

LEXINGTON PENEPLAIN.

The general attitude of the surface on the area of Ordovician rocks is that of a broad plain, above which the hills of the southern part of the area rise abruptly and into which the large streams have cut deep, narrow gorges. The smaller streams have not been able to lower their channels fast enough to keep pace with the main streams, and hence they enter the main streams with a very steep gradient, in places broken by falls and rapids.

There is locally an apparent parallelism of the plain surface and the bedding of the Ordovician rocks, which might suggest that the uniform height of the plain was due to a layer of hard rock; but when traced any considerable distance the surface is seen to cut across rocks of different ages and varying degrees of hardness.

To a nearly level surface produced by subaerial denudation the name "peneplain" is given, and the peneplain formed by the erosion of the Ordovician rocks was called by Campbell[a] the Lexington peneplain.

CRETACEOUS PENEPLAIN.

On the southern margin of the area the hills rise to a fairly uniform height of 500 feet above the Lexington peneplain, and this has led to the belief that they are remnants of an earlier peneplain. No part of the surface of this older peneplain is visible to-day, but its existence is inferred from the uniformity in the height of the hills, which are capped by rocks of different lithological character. This peneplain was referred by Campbell[b] to the Cretaceous.

CAVERNS.

In limestone rocks of uniform character and similar jointing, the rate of cavern formation depends largely upon the topography. Where the surface is rolling a smaller percentage of the rainfall enters the ground than where it is flat. Thus, the Lexington peneplain, with its nearly level surface, must have furnished exceptionally favorable conditions for the formation of caverns and the development of underground drainage systems.

The flat-topped remnants of the peneplain in Woodford, Franklin, and Fayette counties have the largest underground systems of drainage and supply the most copious springs of the region. Unfortunately,

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.
[b] Op. cit.

few of these caverns are accessible, and their size and the extent of their ramifications can be inferred only by the size of the springs and the number and size of the sink holes. On these flat-topped divides there is practically no surface drainage, and the topography is marked by a series of sink holes which receive a large part of the rainfall. It is probable that before the uplifting of the Lexington peneplain a large part of the surface was drained by underground streams, just as the divides are at the present time, and that the Neocene was the period when the formation of caverns was most rapid. Before the peneplain was uplifted the surface drainage was probably limited to the large streams and their principal tributaries. With the uplifting of the peneplain the surface drainage became more extensive and the areas of underground drainage were gradually restricted, but the formation of new caverns and the enlargement of the old has continued down to the present time.

SOILS.

CLASSIFICATION OF SOILS.

Since the time of the first settlement the Blue Grass region has been famous for its excellent soils, but considering the region as a whole the soils vary greatly in different localities, the finest types occurring in areas where the Lexington limestone forms the surface rock.

On the basis of origin the soil of the Blue Grass region may be said to include two types—residual and transported. The residual soils have resulted from the decomposition of the underlying rock and remain where they were formed. The transported soils are made up of disintegrated or decomposed rock particles and have been brought to their present position by the action of wind, water, or ice.

The sand dunes that occur in limited areas along the Ohio Valley and possibly the loess in the northern part of the region represent wind-transported soils. Some writers, however, would class the loess with water-transported soils.

The sands and gravels along the rivers form water-transported soils and are the result of mechanical disruption rather than chemical decomposition. In the valleys of Licking and Kentucky rivers these soils consist of assorted materials derived from the residual soils of the upland, but along Ohio River they were deposited by the flood waters which came from the melting of the continental ice sheet. As would be expected, the soils of the Ohio Valley are composed of the disintegrated fragments of various kinds of rock.

As the rocks of the region include limestones, sandstones, and shales, it might be expected that each kind of rock would yield a residual soil distinctive in type, but this is not always the case. Residual soils from limestones are largely due to solution, and this chemical action

leaves behind it the insoluble sand and clay which was in the original rock. A soil derived from the calcareous shale may be much the same as one derived from a clayey limestone, and a calcareous sandstone may produce a soil which differs little from one derived from a siliceous limestone. The formation of the limestone soils requires the decomposition of a large amount of the original rock, for the sand and clay which make the soil usually form but a small percentage of the rock. The formation of soils from the shales or sandstones requires little besides the mechanical disintegration of the rock and very slight loss of volume results.

The statement made by many geologists that, as the residual soils are derived from the underlying rock, a geologic map is a good soil map, may or may not be true, depending entirely upon the units chosen as a basis for mapping If the formation mapped is in part siliceous limestone and in part argillaceous limestone, the soils from these two phases of the same formation may differ from each other more than they differ from the soils derived from sandstones and shales, respectively.

The classification of soils into types may also be based on texture, structure, color, content of organic matter, topography, and similarity of origin. The most important properties used in determining the soil type are the texture, which depends on the size of the soil particles, and the structure, which depends on the arrangement of these particles. Where a number of types are so closely related in source of material, method of formation, topographic position, and color that they grade one into another, they form a soil series. The soil series of the Ordovician limestones and interbedded shales has been called by the United States Bureau of Soils[a] the Hagerstown series.

In the Blue Grass region the types based on texture include stony clay, loam, and clay, and there are in addition phases of sandy loam and small areas of clay loam. The correlation of the Blue Grass soils derived from the Ordovician formations has not yet been completed, but they represent various textures which agree roughly with the textures of the different types in the Hagerstown series.

DISTRIBUTION OF SOILS.

The stony clay is found over considerable areas of the Eden shale and Maysville and Richmond formations. It consists of a clayey soil containing many fragments and occasional outcrops of limestone, and it occurs on the valley slopes in eroded areas of the formations mentioned. This soil produces good crops of corn, wheat, and tobacco, but its stony character and its marked tendency to erode adapts it better to grass and timber.

[a] U. S. Dept. Agr., Bureau of Soils, Soil Survey Field Book, 1906, pp. 124–127.

The sandy loam found in the Ohio Valley is formed from the alluvium of the terraces. In some parts of the Ohio Valley the sand of the terraces has been reworked by the winds and formed into ridges and dunes. The sandy loam also occurs on the sandstones of the Waverly shale and in places on the Garrard sandstone member of the Eden shale, this phase being derived from the disintegration of the sandstones. In the Ohio Valley this soil occupies areas of slight relief and is subjected to little erosion, but the residual soils of the sandstones commonly occur in deeply dissected areas and are subject to rapid erosion. Soil of this type is well adapted to truck farming, but is rather too light and sandy for general farming. The sandy loam of the Garrard sandstone member of the Eden shale is said to produce good crops where the land is not too hilly for successful cultivation.

The loam soils of the Blue Grass region occur on the Lexington and Highbridge limestones, and in limited areas on the more calcareous phases of the Maysville and Richmond formations. Small areas of loam are also found in the Ohio Valley. The upland loam is derived from the decomposition of the Ordovician limestones, and is the finest blue-grass soil. It has gently rolling topography and is adapted to a large variety of crops, the principal ones being blue grass, corn, wheat, tobacco, and hemp. This soil, especially where derived from the Lexington limestone, produces fine blue-grass pastures, and on it are located the breeding farms which have made Kentucky famous for fine horses. The small areas of loam in the Ohio Valley are well adapted to general farming, but they do not equal the upland areas in value.

The clay soils occupy large areas on the Maysville and Richmond formations, the Eden shale, the Winchester limestone, and Siluro-Devonian rocks, and small areas also occur in the Ohio Valley. These soils vary greatly in value, the best types being formed from the decomposition of the rocks of the Maysville, Richmond, and Winchester formations. The topography of the areas of clay soil varies greatly. The best soils are usually situated in the gently rolling areas. On the soils derived from the Winchester limestone corn, tobacco, hemp, and grass are the principal crops. The Maysville and Richmond soils produce excellent crops of corn, wheat, and tobacco, some of the hilly areas being noted for their fine, white, burley leaf. The soils derived from the Siluro-Devonian limestones are excellent, being well adapted to general farming and producing good crops of corn, wheat, and grass. The shales of the Siluro-Devonian formations, however, yield a very poor soil, which is used for general farming. The Eden shale usually occupies hilly areas, and its soils are among the poorest in the region. They are subject to rapid erosion and are best adapted to the production of

grass and timber. In many parts of the area the attempts to farm these soils are being abandoned, and they are being converted into pastures.

The loesslike silt-loam soils are intermediate in texture between the loam and clay loam. They consist largely of silt, with clay and sand and smaller quantities of materials of a coarse grade. These soils occupy a strip along the uplands bordering Ohio River and are locally of considerable value for agricultural purposes, especially in northern Boone County. In most places the area occupied by these soils does not exceed 4 or 5 miles in width, and it is nearly everywhere underlain by glacial materials, although it reaches a short distance beyond the glacial boundary and laps over the area of residual soils. The material is ordinarily not more than 3 feet thick, although in some places it may be 5 or 6 feet thick.

TEXTURE.

The great value of the soils of the Blue Grass region has been attributed to the composition of the rocks from which they are derived, but there are many other factors that affect their value. The most important of these are the texture and the drainage. The texture of the soil depends upon the size of its particles, and this is determined by means of a mechanical analysis. The following table shows the size of the soil particles in the Hagerstown soil types as determined by such analyses. Although the samples for these analyses were not all taken from the Blue Grass region, they are believed to be fairly representative of the principal soil types which occur on the Ordovician rocks of the area. The presence in the soil of a small amount of carbonate of lime causes the aggregation of some of the soil particles, and thus their character is slightly modified, but the aggregation is probably not sufficient to make any great change in the physical composition of the soil.

Even when a liberal allowance is made for the increased size of the soil grains due to aggregation of the smaller particles, it is clear that the openings in such fine-grained material must be very small. These small openings prevent the soil from absorbing water rapidly, but give it a great capacity for retaining moisture and bringing it within the reach of the plant roots by capillary action. The small size of the pores also brings the ground water in contact with a large amount of soluble material and thus favors the solution of the phosphorus and other elements of plant food contained in the rocks.

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TABLE 2.—*Textures of the Hagerstown soil types.*

[Compiled from the U. S. Department of Agriculture, Bureau of Soils Field Book, 1906, pp. 124–127.]

	Fine gravel, 2–1 mm.[a]	Coarse sand, 1–0.5 mm.	Medium sand, 0.5–0.25 mm.	Fine sand, 0.25–0.1 mm.	Very fine sand, 0.1–0.05 mm.	Silt, 0.05–0.005 mm.	Clay, 0.005 mm. or less.
Hagerstown stony loam:							
Soil	[b]2	4	3	6	11	52	22
Subsoil	2	3	2	4	7	38	44
Hagerstown stony clay:							
Soil	1	5	5	10	5	29	45
Subsoil	1	2	2	5	4	28	58
Hagerstown sandy loam:							
Soil	1	6	8	24	15	32	13
Subsoil	0	3	4	14	9	31	38
Hagerstown loam:							
Soil	5	3	3	7	10	46	28
Subsoil	2	3	2	6	8	38	39
Hagerstown clay loam:							
Soil	1	3	2	5	9	64	16
Subsoil	3	2	2	4	10	51	28
Hagerstown clay:							
Soil	1	2	2	9	8	41	38
Subsoil	0	1	1	6	5	29	56

[a] The figures at the top of the columns refer to the diameter of the soil particles.
[b] The figures in the various columns give the percentage of the grains of different diameters.

DRAINAGE.

Another factor which influences the value of the soils of the Blue Grass region is the excellent underdrainage provided by the crevices and channels in the rock. Indeed, if it were not for the removal of the excess of moisture through the underground drainage channels the fine-grained soils of the region would soon become so filled with water that plant growth would be greatly hindered.

CHEMICAL COMPOSITION.

The remarkable fertility of the Blue Grass region soils has generally been attributed to the compounds of phosphorus contained in considerable quantities in the Ordovician limestones. Although the value of the phosphates is unquestioned, other elements are recognized as important to soil fertility. Carbon, one of the principal elements which enter into the composition of plants, is supplied chiefly by carbonic acid from the air. Oxygen and hydrogen, the other elements which are abundant in plants, are supplied by water. In addition to the elements mentioned above, certain other substances, the most important including calcium, magnesium, sulphur, iron, nitrogen, phosphorus, and potassium, must be obtained from the earth. Some of these are needed by plants in such small quantities that most soils contain an ample supply, but the last three are of such essential value that it may become necessary to add them to poor soils in order to produce large crops.

The following table of analyses shows that the elements which enter into plant composition are so abundant in most Kentucky soils that it is unnecessary to add fertilizers. The amount of nitrogen

in the soils was not determined, but as it is largely supplied by organic matter, it is safe to conclude that where the analysis of Blue Grass soils shows a large amount of organic matter, the supply of nitrogen will usually be ample. In many soils this organic matter represents the accumulation of long ages preceding the advent of civilized man and the beginning of cultivation in this region. As the nitrogen is required to produce plants, careful treatment is necessary to restore nitrogen or organic matter to the soil.

The phosphorus and potash in most of the soils were supplied by the decomposition of the calcareous rocks of the region, and the amount of each was determined by the composition of the original rock. Thus, the decomposition of the phosphatic limestones has produced soils rich in phosphorus. The amounts of potash and phosphorus (stated as phosphoric acid in the tables) should be compared with the amounts in Hilgard's averages of 466 soils from the humid region of the United States, which are also shown in the table. The States represented in making up Hilgard's averages and the number of analyses of soils from each are as follows: North Carolina, 20; South Carolina, 11; Georgia, 40; Florida, 7; Alabama, 50; Mississippi, 97; Arkansas, 38; Kentucky, 185; and Louisiana, 18. Although Kentucky soils averaged outnumber those from any other State, the best Kentucky soils were not included, because it was desired to use only those soils which were not derived from limestone.

A careful comparison of the analyses of Kentucky soils and the averages given by Hilgard shows that Kentucky soils as a whole are richer than the average in those mineral elements which support plants. While the siliceous Waverly and siliceous mudstone (probably Eden shale) soils are low in the elements of plant food, the soils of the Lexington (Trenton) and Panola ("Corniferous") formations are very much richer than the average, and practically all of the analyses appear to represent soils which are better than the average given by Hilgard. In comparing the analyses of the soils of the Blue Grass region with each other the superiority of the Lexington (Trenton) soils is very evident. From an examination of the list of analyses used in making the averages, it appears probable that some analyses of Winchester and Maysville limestone soils were included in the averages of Lexington (Trenton) soils. This, since the Winchester and Maysville limestone soils are, in general, poorer than those of the Lexington (Trenton), probably means that the averages are lower than if the analyses were entirely from the Lexington soils. Notwithstanding this fact, the analyses show that the soils are very rich in plant food, and experience has shown that their natural productivity is high.

TABLE 3.—*Chemical composition of Kentucky soils.*[a]

	Moisture.	Insoluble residue.	Organic and volatile matter.	Oxides of aluminum, iron, and manganese.	Calcium carbonate ($CaCO_3$).	Magnesium oxide (MgO).	Phosphoric anhydride (P_2O_5).	Potash (K_2O), extracted by acids.
Average of 3 Ohio Valley alluvial soils	2.51	84.31	3.47	9.84	0.10	0.19	0.12	0.45
Average of 21 Quaternary (loess) soils	2.27	88.10	2.94	6.94	.37	.29	.12	.26
Average of 10 Waverly soils		89.91	4.10	4.29	.14	.26	.10	.15
Average of 9 black slate soils		80.13	5.93	10.59	.48	.52	.23	.18
Average of 15 "Corniferous" limestone soils		83.52	5.07	9.06	.47	.63	.28	.34
Average of 16 Upper Silurian soils		82.40	6.23	10.49	.32	.42	.19	.24
Average of 11 siliceous mudstone (middle Hudson) soils		86.55	4.78	7.06	.10	.60	.16	.16
Average of 32 Trenton ("Blue") limestone soils		73.38	6.21	11.20	.75	.64	.33	.40
Average of 6 Birdseye limestone soils		85.80	4.45	6.51	.45	.38	.21	.18
Average of 234 Kentucky soils		84.63	4.47	8.00	.36	.34	.18	.26
Average for humid region[b]	4.65	84.03	3.64	7.56	[b].20	.22	.11	.22

[a] Peter, Robert, The composition of the soils, limestones, clays, and marls of Kentucky: Kentucky Geol. Survey, 2d ser., pt. 13, vol. 5, 1885, p. 113.

[b] Hilgard, E. W., A report on the relation of soil to climate: Weather Bureau Bull. No. 3, 1892, p. 30. The figures given above are adapted from Hilgard's table; lime (presumably CaO) has been calculated to $CaCO_3$ for comparison with Peter's figures.

The Panola ("Corniferous") soil appears to be exceptionally good and to approach most nearly the high average of the Lexington limestone soils. The Highbridge (Birdseye) and Panola (Upper Silurian) soils have about the same general composition, although derived from rocks which widely differ in age, in appearance, and probably also in composition. It is interesting to note that the Ohio shale (black shale) soils, which have often been considered very poor, approach the average soils in composition. In one of the early reports of the Kentucky Geological Survey[a] Doctor Peter attributed the low productivity of this soil to the presence of too much water and suggested the use of lime to render the clay more porous, so that the excess of moisture could escape. The loess soils, which are fair when measured by the standards of the average soils, are considerably poorer than the Lexington (Trenton) soils.

SURFACE WATERS.

OHIO RIVER.

The Ohio makes a bend northward around the Blue Grass region, flowing north of west from Maysville to Cincinnati and approximately southwest from Cincinnati to the southern boundary of Old-

[a] Peter, Robert, Chemical analyses, A, pt. 2, Kentucky Geol. Survey, 1883, p. 101.

ham County, and forming a partial boundary of 10 out of 30 counties. Only a small portion of the area, however, drains directly into the Ohio, most of the drainage passing first to one of the principal tributaries. Where the river borders this region its channel is a trench cut into the Ordovician rocks to a depth of 350 to 400 feet and varying in width from one-fourth mile to 1½ miles. The variation in width of the Ohio channel is the result of the formation of a single stream channel out of a number of segments of different streams and tributaries.

Between Maysville and Louisville,[a] a distance of 198 miles, the Ohio falls 54 feet, an average fall of 0.27 foot, or somewhat more than 3 inches, to the mile; but the rate of fall of the river is not uniform, varying from 0.2 foot to at least 5 feet to the mile in different parts of its course, increase in fall commonly occurring where the river crosses the old rock divides. The velocity of the stream is variable but is nowhere high.

Most of the small streams of the region are steep walled and have very high gradients, and the consequent rapid run-off causes correspondingly rapid fluctuations in the amount of water entering the main streams. Floods are very common on the Ohio, the gage records at Cincinnati showing that the river has passed the danger line (50-foot stage) just 23 times in the forty-six years previous to 1906. The highest stage during this period was 71.1 feet, in February, 1884, and the lowest was less than 2 feet. The extreme range is therefore nearly 70 feet, but the usual range is probably not much more than 25 feet. The highest floods, as a rule, occur in winter—in February or later—and are caused by the melting of the snow. A second rise, produced by the summer rains and ordinarily less than the one occurring in the winter, takes place in May or June. The autumn rains produce a third rise, which is comparatively small. The date of the autumn rise is uncertain, as it may come in November or not until late in December. The lowest river stages are, as a rule, reached in August or September, and they generally extend into October. As a result of recent work by the United States Government, the Ohio is now navigable along the borders of the Blue Grass region, even at very low water.

KENTUCKY RIVER.

Kentucky River rises in the mountainous part of the State and flows in a general northwesterly direction across the Blue Grass region, passing near the apex of the Jessamine dome. Where the river crosses the resistant Highbridge limestone its gorge is generally but little wider than the stream, and in many places the river flows between

[a] Gannett, H., Profiles of rivers in the United States: Water-Supply Paper U. S. Geol. Survey No. 44, 1901, pp. 41–43.

perpendicular walls of the limestone 300 feet or more in height. A characteristic view of this gorge is shown in Plate III, A. At various points above Frankfort the stream is bordered by rock terraces bearing narrow strips of alluvium, in most places composed of fine sand with a few layers of pebbles. Below Frankfort the alluvial deposits are more extensive, locally forming bands more than one-fourth mile wide. In areas where the Kentucky flows through rocks of the Maysville, Eden, and Winchester formations the slope of the channel is as a rule comparatively gentle. The contrast between the precipitous walls formed by the Highbridge limestone and the gentle slopes of the walls in the Maysville formation is beautifully shown on the northern edge of Madison County, where, by reason of the Kentucky River fault, the river passes abruptly from one of these formations to the other. On the one side of the fault the cliffs are so steep that it is impossible to ascend them; on the other side fields of corn extend down the gently sloping walls to the flood plain of the river. This change from one type of valley to the other is repeated several times as the river meanders back and forth across the fault line.

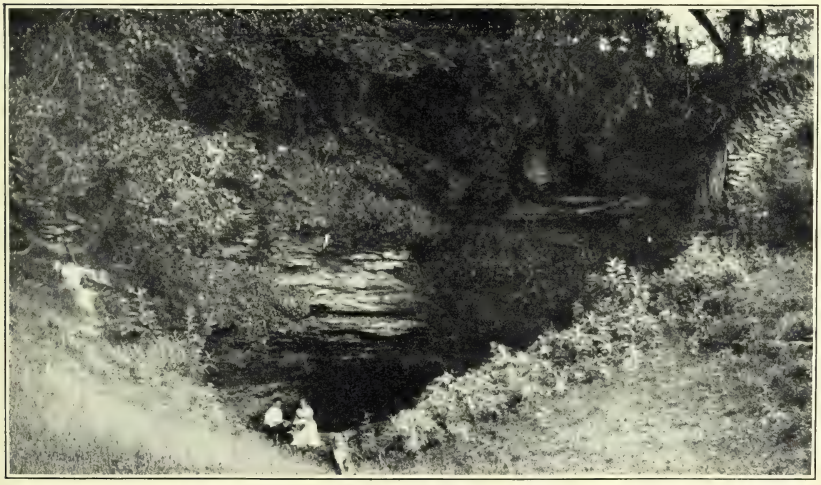
From Frankfort to the mouth of the river, a distance of 65 miles, the Kentucky falls 42 feet, or 7.2 inches to the mile; between Frankfort and Beattyville, a distance of 189 miles, the fall is 184 feet, or at the rate of nearly 1 foot to the mile. Throughout the Blue Grass region the gradient of this stream is comparatively low, but toward the mountains it increases rapidly.

The largest tributaries of the Kentucky in the Blue Grass region are Dix River and Eagle Creek, both of which have higher gradients than the main stream at the points of junction. The fall of Dix River from a point west of Lancaster to the mouth of the stream, a distance of 10 miles in a direct line, is not far from 300 feet. The minor branches of the Kentucky and its principal tributaries have very steep gradients, some of them descending 300 feet or more from the level of the upland to the main stream in a distance of 3 or 4 miles. As a result of the high gradients the streams show quickly the effects of rains, the water reaching maximum heights within a very short time after a storm. Floods are very common on the Kentucky, though the range in stage is probably not great as compared with that of the Ohio at Cincinnati.

LICKING RIVER.

Licking River heads at the edge of the mountains and flows in a direction slightly west of north into Ohio River opposite Cincinnati. This stream has cut through the Ordovician rocks to the Lexington limestone and the channel is in many places steep walled, but it is, as a rule, bordered by deposits of alluvium, especially along the lower course of the stream.

A. KENTUCKY RIVER GORGE SOUTH OF CAMP NELSON, KY.



B. AN OPEN SINK HOLE IN CLARK COUNTY, KY.

The gradient of Licking Valley has not been determined, but it is apparently somewhat greater than that of Kentucky River. The tributaries of the Licking, like those of the other streams of the region, have very steep slopes.

MINOR STREAMS.

A small strip along the western edge of the Blue Grass region is drained by Salt River. The streams belonging to the Salt River system are all small, most of them flow only a part of the year, and all of them fluctuate rapidly with the amount of rainfall.

UNDERGROUND WATERS.

THE SOURCE.

The water that falls upon the land in the form of rain or snow either sinks into the earth or flows off over the surface. The part which sinks into the ground and is held by the rocks is known as ground water; that which flows off over the surface, together with the ground water returned to the surface streams, forms what is called the run-off. A part of both ground water and run-off is returned to the atmosphere and another part is consumed in chemical and organic work.

It is easy to understand that the shallow wells derive their supplies from rainfall, for the process of absorption by the more or less porous soils may be observed, and in many places in the Blue Grass region the storm waters may be seen entering the underground channels through sink holes. The connection between rainfall and the water supplied by deep wells is not, however, so apparent, and it is indeed possible that the saline waters furnished by some of the deep wells were taken into the rocks from the ocean during the process of deposition; but disregarding the origin of the very saline waters, it may be said that all of the water found in shallow wells, and much of that in deep wells, is derived directly from rainfall.

CONDITIONS OF OCCURRENCE.

THE WATER TABLE.

The water that sinks into the earth descends until it reaches a level where the underlying rocks are already completely saturated. This level is known as the water table, and its form and depth beneath the surface vary with the amount of rainfall, the relief of the surface, and the resistance which the rocks offer to the movement of the water. In arid regions of low relief the water table lies far beneath the surface, and its form is only slightly convex, the convexity being greatest in the materials that offer the most resistance to the passage of the water. The variation in convexity, which is

due to the resistance offered by the rock to the movement of the ground water, is explained by the fact that a greater slope of the water surface is needed to overcome an increased resistance. In humid regions of considerable relief the water table reproduces with lesser magnitude the inequalities of the land surface. The greater the rainfall and resistance the nearer the approach of the water table to the surface.

Wherever the water table intercepts the surface, as along the valleys of the streams, seeps or springs are formed, and the lowering of the stream channels will depress the water table except where impervious materials, such as shales, are encountered. Where the porous material rests on dense materials, such as shale or clay, the depression of the water table ceases, and as the stream deepens its channel springs are left perched on the side of the valley. Veatch[a] has given the name "perched water tables" to the water tables that are left above the dense materials by the deepening of the stream

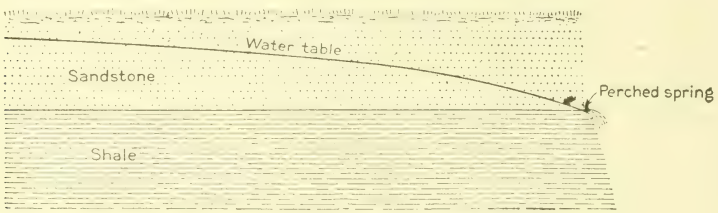


FIGURE 1.—A perched spring.

channels. It is proposed to extend the term "perched" to include springs formed where such water tables intersect or emerge at the surface. Perched springs are common at the contact of some of the sandstone beds of the Waverly shale with the underlying shale beds. They may also occur at certain points along the larger streams where beds of sand and gravel rest on clay.

In a large part of the Blue Grass region there is no general water table, but a water table exists in the sandstones of the Waverly shale, in alluvial materials along the larger streams, and in some partly saturated glacial sands and gravels on the uplands of northern Boone and Kenton counties. Locally, in various parts of the upland, a porous residual soil allows the formation of a ground-water level, but these areas are small and their supply of water is likely to fail during a very dry season.

The passages through which the ground waters move vary with the character of the rock, and in order to understand underground-water conditions it is necessary to consider the mode of occurrence

[a] Veatch, A. C., Underground water resources of Long Island, N. Y.: Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 57–58.

of water in the different kinds of rocks and in rocks of different sorts arranged in alternate layers differing in thickness.

WATER IN SAND, GRAVEL, AND SANDSTONE.

In sand the water moves through the small spaces between the grains; hence the coarser or more porous the material the larger the passages and the greater the amount of water they will transmit.

Slichter[a] explains the effect of the size of the sand grains on the movement of water as follows:

> If the particles of sand or gravel which make up the water-bearing medium are well rounded in form, the pores are somewhat triangular in cross section and the diameter of the individual pores is only one-fourth to one-seventh the diameter of the soil particles themselves. Thus if the individual grains of sand average 1 millimeter in diameter, the pores through which the water must pass will average only one-fourth to one-seventh of a millimeter in diameter. If to a mass of nearly uniform sand particles larger particles be added, the effect on the resistance to the flow of water will be one of two kinds, depending principally upon the ratio which the size of the particles added bears to the average size of grains in the original sand. If the particles added are only slightly larger than the original sand grains, the effect is to increase the capacity of the sand to transmit water, and the more particles of this kind that are added the greater will be the increase in the capacity of the sand to transmit water. If, however, large particles are added, the effect is the reverse. If particles seven to ten times the diameter of the original sand grains be added, each of the new particles tends to block the course of the water. Thus, for example, a large bowlder placed in a mass of fine sand will tend to block the passage of the water. As more and more of the large particles are added to a mass of uniform sand, the rate of flow of water through it will be decreased until the amount of the large particles equals about 30 per cent of the total mass. From this time on the adding of the large particles will increase the capacity of the whole to transmit water, until if a very large quantity of the large particles be added, so that the original mass of fine particles becomes relatively negligible, the capacity to transmit will approach that of the mass of the large particles alone. These facts have an important bearing upon the capacity of gravels to furnish water to wells or to transmit water in the underflow of a river. The presence of large particles is not necessary to be interpreted as indicating a high transmission capacity of the material, for this is indicated only when the large particles constitute a large fractional per cent of the total mass, as would be the case where the large particles equal 40 or 50 per cent of the whole.

Sandstone, having had some of the passages closed by the cementing material that binds the grains together, is less porous than sand composed of grains of the same size and shape. Sandstone therefore offers much greater resistance to the movement of water and transmits a relatively smaller amount than sand. This condition is often partly offset by the joint and bedding planes which may furnish channels for the passage of considerable water.

The motion of underground water is controlled by the factors that govern the motion of surface water—resistance and slope. As the

[a] Slichter, Charles S., Field measurement of the rate of movement of underground waters: Water-Supply Paper U. S. Geol. Survey No. 140, 1895, pp. 10–11.

water which moves in tiny threads between the grains of sand meets with a great deal of resistance it advances but a few feet a day; with the same gradient a surface stream, because of the comparatively slight resistance offered by the channel, will move several miles in the same length of time.

WATER IN LIMESTONE.

JOINTS AND BEDDING PLANES.

Limestone rocks are as a rule traversed by at least two sets of vertical joints which make approximately right angles with each other, and a third set of partings at right angles to these joints form the bedding planes of the rocks. The spacing of joints is ordinarily fairly uniform over considerable areas, and the interval between them is commonly to be measured in feet; but where the rocks have been deformed the joints are more numerous. The bedding planes exhibit very little uniformity of arrangement; an interval of a few inches may be followed by one of much greater magnitude.

Some limestones are sufficiently porous to absorb considerable quantities of water, but most of them are too dense to yield water for wells or springs. The water which comes from limestones is usually that which has found its way in along more or less enlarged joints or bedding planes, the enlargement being due to the solvent action of water. Obviously the places where water circulates most readily will, other things being equal, suffer most loss by solution, but differences in the solubility of the rock may offset the effect of rapid circulation. Doubtless the most common line of rapid solution is at the intersection of a prominent bedding plane and a more or less open joint.

FORMATION OF CAVERNS.

Not only is slight resistance to solution offered along certain lines, but in certain spots, owing to the presence of numerous open joints or to the solubility of the rock, very large chambers—"domes"—are formed. It is noticeable that "domes" are the points at which considerable water enters the underground channel. This water, coming fresh from the surface, is charged with a great amount of carbonic acid and it attacks the limestone about the point of entrance; as it flows farther and farther from the point of entrance it loses its power to dissolve the rock, because it has gradually picked up as large an amount of calcium carbonate as it can carry.

As the belt of rapid solution is restricted to the zone of active water circulation, the formation of caverns takes place largely above the level of the surface streams that receive the underground drainage, but this does not imply that there is no deep-seated solution or that

active circulation may not extend slightly below the level of surface drainage. As solution progresses some parts of the walls and roof of the solution cavities collapse and sink holes are formed. If the channel beneath the point of collapse is large in proportion to the amount of material which falls, the sink is usually an open hole; but if the amount of fallen material is sufficient to clog the channel, the sink appears as a rounded depression that has no outlet. The fallen material may obstruct the opening so that the stream appears at the surface, or it may leave a passage which will allow the drainage to continue underground. In this event the gradual wearing of the stream may remove enough of the fallen material to form an open sink.

In the process of deepening its valley a stream lowers the base-level of its tributaries and thus affords them an opportunity to degrade their channels. When the tributaries flow in caverns they lower their channels along some joint plane, and the process goes forward most rapidly along some particular line in the same manner as during the

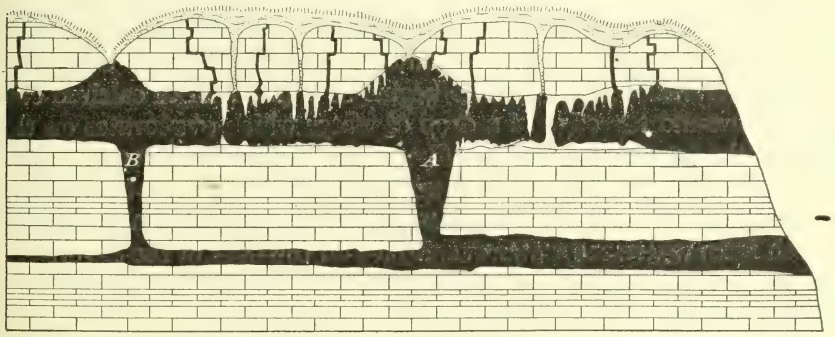


FIGURE 2.—Diagram of a cavern, showing different levels of the underground stream.

formation of the original cavern. At certain places where there is rapid downward movement from the old to the new channel more or less rounded openings develop. These openings provide a passage from the old to the new cavern and are usually called "pits." They often form beneath the domes, their location being determined in part by the presence of initial crevices and in part by the same condition that produced the dome, namely, the entrance of surface water bearing considerable free carbonic acid. (See A, B, fig. 2.) Doubtless the formation of caverns, and especially of pits and domes, is aided by the mechanical action of the water, especially where it contains sediment.

As long as the lower channel or the passages leading to it are comparatively small the old cavern retains a large part of the drainage. With the enlargement of the new cavities the old channel receives less and less of the original drainage, until it is entirely deprived of its original headwaters except during storms, and at last, when the new

channels have become sufficiently enlarged, the old channel receives only the drainage of its local tributaries.

Migration from higher to lower levels may take place at successive periods, leaving a series of abandoned channels at different levels. The course of the underground stream at each successive stage probably deviates more or less from the course of the abandoned channel. Moreover, the course may not lie in a single channel, but passages may divide and reunite, forming a more or less extensive network of channels.

After a section of the underground stream has been abandoned the amount of water entering the old channel becomes less and less until it is chiefly confined to small seeps. At this stage much of the water is removed by evaporation, so that solution gives place to deposition, the principal deposit being calcium carbonate. At first deposition is rapid, because the crevices are large enough to supply all the water that can be evaporated; but gradually, as the openings become closed, the rate of deposition decreases. The deposits present a great variety of forms which add to the beauty of the caverns. The most common types, the stalactite and stalagmite, are familiar to all who have visited caverns. The stalactite begins as a thin film of calcium carbonate around the edge of a drop of water which evaporates on the roof of the cavern. Upon this film as a nucleus successive additions are made until the stalactite resembles a giant icicle suspended from the roof of the cavern. The accumulations of calcium carbonate which form where the water evaporates on the floor of the cavern are known as stalagmites. By the union of stalactites and stalagmites pillars are formed.

If a shale bed is encountered by the water in its downward progress a cavern is usually formed above it, and if the shale bed is some distance above the level of the surface stream which receives the drainage from the cavern the water may emerge from the cliff above the surface stream. The mechanical wear of the underground stream may remove the shale at some point, and thus permit the formation of another cavern nearer the level of the surface stream. If the shale bed is of considerable thickness the downward migration of the water may be permanently obstructed. The lowering of the channels of the surface streams usually takes place much more rapidly than the lowering of the underground streams. In consequence of this fact the underground streams may remain considerably above the level of the surface streams even where there are no beds of shale or other dense material to prevent downward migration.

SMALL WATER PASSAGES.

In all limestone regions there are water passages below the levels of the surface streams. In some places the openings are simply small

pores in the limestone, but in the Blue Grass region they appear to be channels which closely resemble the caverns. Vein deposits are formed in these passages, and where exposed by erosion they present forms closely resembling those found in ordinary caverns. When penetrated by drilling the small water passages supply an abundance of water which is usually under considerable head, indicating that the channel is covered by impervious rock. The direction of movement in these channels probably conforms roughly to the dip of the rock, which in the Blue Grass region is away from the apex of the Jessamine dome. In this region these channels usually contain water that is more highly mineralized than that of the caverns.

WATER IN SHALE.

Shale, being composed largely of clay, contains practically no available water except that found in the joints and bedding planes. The number and character of the joints and bedding planes in shale vary in different formations and in different parts of the same formation. The water that enters the joints of the shale passes downward to the zone at which these openings practically cease and then moves laterally until it reaches the point of emergence. Near the surface the bedding planes may be sufficiently open to allow the passage of considerable water, but at moderate depths they are closed so that they transmit little or no water.

WATER IN INTERBEDDED LIMESTONE AND SHALE.

The amount and mode of occurrence of underground water in interbedded limestone and shale vary greatly with the relative amounts of the two kinds of rocks and the relations they bear to each other and to the surface. In a formation with a high percentage of limestone and thin scattered beds of shale the underground circulation is essentially the same as that in pure limestone; in a heavy deposit of shale containing thin beds of limestone underground water occurs essentially as in shales. For the sake of simplicity consideration will here be restricted to the occurrence of water in a series consisting of equal parts of shale and limestone arranged in alternating layers not exceeding 6 inches in thickness. Under such conditions the surface water may penetrate the rocks by passing along the joints which cross the beds, or it may follow along a joint in one or more beds, thus conforming to the dip of the rock. Probably in most such formations the actual movement combines these two methods. Water enters a joint near the surface and percolates downward until its course is obstructed by the gradual decrease in the width of the opening. If there were no means of escape laterally the movement would cease as soon as the crevice was filled; but in

general a lateral movement along the joint allows a slow movement of the water. The lateral movement naturally follows the largest crevice, and this may lead to frequent change from one series of joints to the other, or the movement may continue along a single joint.

The movement of the water tends to enlarge the joints by mechanical wear, but as the circulation is usually slow the amount of enlargement is slight. The solvent power of the water tends to enlarge the joints along the beds of limestone, but as these beds are thin the height of the channel produced by solution is small.

The tendency of the shale to sink into any cavity which may be formed by solution restricts the width of the channel. The lenticular shape of many of the limestone beds presents another obstacle to the formation of underground passages by solution. As a result of all these factors the underground channels in interbedded shales and limestones are small.

Where the downward movement of the water is checked by a heavy bed of shale the water usually follows the dip of the shale bed, and under some conditions this movement may be away from the surface stream. An example of such movement was noted in northwestern Franklin County. Where the water follows the dip it is generally confined by the overlying shale and it continues its underground course until it reaches some point of escape at lower level.

The occurrence of springs above the level of the main streams was mentioned in connection with the formation of caverns, but it needs special mention here because such springs are very common in formations consisting of interbedded limestones and shales. The water which enters the joints passes downward until it reaches a layer of shale which contains no crevice, and follows this layer to the point at which it emerges at the surface. The most usual course for the water which supplies these springs is along the contact of a limestone layer with the underlying shale. These springs are most common along Ohio River, but they occur also along the other streams in the Blue Grass region. Their height above the streams varies from a few feet on some of the smaller streams to more than 300 feet along the Ohio and other large rivers. These springs have the same topographic position as the perched springs, but the mode of occurrence of the water is different.

SPECIAL CONDITIONS IN THE BLUE GRASS REGION.

WATER IN THE HIGHBRIDGE AND LEXINGTON LIMESTONES.

Water channels.—The Highbridge limestone forms the surface rock in but few localities in the Blue Grass region, and in those areas the topography is rugged and the soils are as a rule thin. The formation

therefore contains but few large underground streams; most of the water channels in it are small. Along Kentucky River gorge, however, some of the channels form good-sized caverns, those best known being at Glasses Mill, Valley View, Highbridge, and Camp Nelson.

The Lexington limestone, except in the vicinity of large surface streams, occupies areas having gently rolling topography and a heavy deposit of porous soil. These conditions favor the occurrence of a large amount of underground water and the development of extensive systems of underground drainage, and the formation contains innumerable small channels and many large caverns. Indeed, most of the counties in which this limestone covers a large area can boast one or more caverns. The best known, and probably the largest of these, is the Russell cave, in Fayette County, which is reported to have been explored for nearly a mile. Several of the other caverns in the Lexington limestone have been explored shorter distances. Most of these caverns contain streams, many of which give rise to large springs. Few of the caverns are accessible except in dry weather, and none of them are highly ornamented by stalactites or

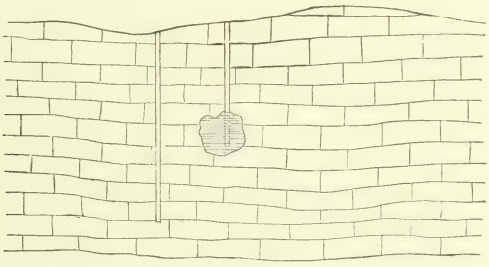


FIGURE 3.—Diagram showing difference in conditions in adjacent wells in limestone.

other deposits. The small underground channels that lie above the level of surface drainage also give rise to many springs. Below the level of the surface drainage the underground channels in the Lexington limestone are apparently small, but most of them seem to be full of water, while the channels nearer the surface are practically never entirely filled.

Wells.—The Highbridge limestone is penetrated by but few shallow wells and most of the deep wells sunk in it obtain mineral water. More than 95 per cent of the drilled wells of the upland obtain water from the Lexington limestone. The possibility of procuring water depends entirely on the chance of encountering one of the underground channels. In some localities few wells fail to procure an adequate supply; in others many failures are reported. The mode of occurrence of the mineralized waters makes it uncertain whether they will be encountered in any particular well, and in two wells located near together they may be found at very different depths (fig. 3).

In general they may be looked for at less depth in the valleys than on the hills, but to this rule there are likely to be many exceptions. Wherever the Lexington and Highbridge limestones are covered by younger formations they yield only the highly mineralized waters. Ignorance of this fact has led to the sinking of deep wells in the areas of Maysville limestone with the hope of obtaining waters for domestic and industrial uses. Such wells are almost certain to be failures.

Quality of the water.—The water in the channels which are situated above the level of the surface drainage is practically always hard, but the hardness varies with the amount of rainfall, being greatest in dry weather and least after heavy rains. This condition is readily explainable, for in dry weather nearly all the water seeps in through the soil and the velocity of the underground stream is low, while during heavy rains much water enters through open sinks and the stream velocity is high. When the water enters from the soil, the subsoil, or the underlying rock it contains carbonic acid, which enables it to dissolve the material in the residual deposits and the limestone. The slow movement in the underground channel facilitates solution, but when the water enters through open sinks it contains less carbonic acid and the rapid movement of the flood waters does not favor solution. The substances most commonly found in the shallow waters are calcium and magnesium, but a number of other substances are present in smaller quantities.

The plane of separation between the shallow and deep waters coincides roughly with the levels of surface drainage, rising slightly above the level of the surface streams toward the divides and sinking slightly below the streams in the valleys. Where the surface streams flow in canyons the deep waters are often found above the levels of the surface streams. The deep waters in the Lexington and Highbridge limestones always contain considerably more mineral matter in solution than the shallow waters, and some of them appear to contain alkaline carbonates. (See analyses Nos. 24 and 25, p. 212.) These highly mineralized waters, which for the sake of brevity will be termed "mineral waters," occur in small areas of porous limestone or in channels that pass below the levels of the surface drainage. Rapid movement of the underground water is prevented by the situation of the channels and porous rock, and in many places the water is probably stationary; thus the water may remain in contact with the rock for a long time and dissolve out much mineral matter. Such waters are especially likely to be brackish or salt and to contain hydrogen sulphide or petroleum.

Practically all the channels are supplied with water from the surface, and when penetrated by wells the mineralized water may be replaced by the ordinary hard limestone water after the well has been pumped for a time. The length of time required to make this change

varies from two or three weeks to a year or more, being influenced by the rate of pumping, the size of the channel, and the distance of the well from the point at which the water enters the ground. Rarely the character of the water does not change after long-continued pumping.

The numerous joints in the limestone probably furnish a natural means of escape for the mineral waters, but the amount escaping from a channel must as a rule be less than that taken out by an ordinary well. The almost universal connection of the channels with the surface, which is indicated by the entrance of surface water after pumping, shows that the water is probably derived from meteoric sources, the mineralization being due, as suggested, to the slow circulation of the water and the great length of time it remains in contact with the soluble materials of the limestone.

Within 10 or 15 miles of Kentucky River the shallow waters have been moving downward during the erosion of the gorge of that stream. This movement, which has been accomplished in the manner described under the occurrence of waters in limestone, has made it possible to procure some ordinary hard water below the level of the surface streams. Where the channel containing the mineral water has been severed by the deepening of the main stream and water from the surface allowed to enter, the result has been the same as when one of these channels has been penetrated by a well and the mineral water has been removed by pumping.

The general movement of the deep water appears to be in the direction of the dip of the rocks, and consequently the mineral waters of the region pass outward from the central area of the Highbridge and Lexington limestones. This outward movement carries the mineral waters into those areas where the Lexington and Highbridge limestones lie beneath the younger geologic formations.

WATER IN THE WINCHESTER LIMESTONE.

Water is found in the Winchester limestone under conditions resembling those in the Lexington limestone, except where the formation contains a high percentage of shale. Channels of sufficient size to be called caverns are not known in this formation, but where the limestone layers are exposed at the surface they yield, as a rule, considerable water.

The shallow waters of the Winchester are the ordinary hard waters of limestone rocks; the deep waters are saline and locally contain hydrogen sulphide.

WATER IN THE EDEN SHALE.

The outcrops of Eden shale occur in areas of rugged topography unfavorable for the absorption of large amounts of water. The formation presents three phases: (1) Nearly pure shale, (2) interbedded

shale and limestone, and (3) sandstone. All of these rocks except the sandstone yield on weathering a dense residual clay which stores considerable moisture, but allows only a small portion of it to reach the underground channels. The residual materials of the sandstone are porous loams or sandy loams, through which considerable water passes to the underlying rocks.

In the shaly phase of the formation the water occurs in numerous joints, few of which, however, are large. The bedding planes are practically everywhere too compact to yield water. The amount of water afforded by the shale is usually small and the supply is quickly reduced by dry weather. The water is also liable to pollution from surface drainage and much of it is of poor quality.

The interbedded phase varies from nearly pure shale to shale containing numerous limestone layers, and the water conditions vary correspondingly. The most abundant supplies of water are obtained where one or more beds of limestone occur near the surface. In such places the water comes chiefly from the enlarged joints in the beds of limestone.

The sandy phase of the formation—the Garrard sandstone member—varies from slightly sandy shale to nearly pure sandstone, with shaly sandstones predominating. The more shaly parts of the sandstone yield very little water except along the joints, and the amount is variable. The sandstones, where not too firmly cemented, yield moderate quantities of water, and where exceptionally thick the supplies may be large. The concretionary sandstone is, as a rule, too dense to be water bearing.

The joints of the Eden shale seldom present openings which yield water at depths greater than 25 feet, and the depth of wells should not exceed 35 feet. Moreover, experience has shown that the largest supplies occur near the surface. Dug wells are more successful than drilled wells, because they intersect a larger number of joints. No deep wells obtain water from this formation. As the water comes from the immediate vicinity of the well and receives practically no purification, great care should be exercised to guard the wells from pollution.

Springs are numerous in the Eden shale, but none of them are of large volume and few can withstand the effect of drought. Some exceptionally good springs were observed in the sandstones of Garrard County.

The water of the shaly phase of the Eden contains only a small amount of mineral matter and is moderately hard, but where limestone beds occur the mineral content of the water is increased and the hardness may be equal to that of the shallow limestone waters. Much of the water of the sandy phase of the Eden is nearly free from

mineral matter and is called "soft," but the presence of lime in the sandstone may cause it to yield hard water.

WATER IN THE MAYSVILLE AND RICHMOND FORMATIONS.

The outcrops of the Maysville and Richmond formations have a gently rolling surface over considerable areas, and the topography thus favors the retention of residual soils and the absorption of large quantities of water. The soils are somewhat porous where they are derived from the limestone layers of the formations, but are dense where they result from the disintegration of the shales, and they therefore have lower storage capacity for water than the soils of most limestone areas.

Underground water occurs in the Maysville formation essentially as in interbedded limestones and shales. The more shaly parts of the formation present conditions much like those in shale; where the formation contains heavy beds of limestone which are near the surface, the underground water conditions resemble those in limestones. Thus, although certain parts of the Maysville contain but little more water than the Eden shale, there are other parts in which small caverns are found, and these parts supply considerable water. The presence of the caverns is usually indicated by a number of small sinks, which are especially noticeable near Burlington, in Boone County, although they may also be found in many other parts of the area. Locally, these heavy beds of limestones are capped by several feet of shale, and where this occurs the limestones receive very little water. Such conditions obtain in the vicinity of Richmond, Madison County.

Water conditions in the Richmond formation are much like those in the Maysville, but as at many places the Richmond carries much shale the amount of its underground water is locally small. The heavy beds of limestone in the upper part of the Richmond afford conditions favorable for the formation of caverns, and numerous sinks and springs indicate the presence of large underground channels. This phase of the Richmond formation is practically restricted to western Trimble and Oldham counties.

Drilled wells in the Maysville and Richmond formations have been remarkably successful in some localities, a well in the vicinity of Flemingsburg, Fleming County, affording a conspicuous example. In general, however, there is small chance of obtaining enough water for a farm from drilled wells in either of these formations. It is seldom advisable to sink a well more than 50 feet, and 100 feet should be the maximum, because in the interlaminated limestones and shales of the two formations the number and size of the openings decrease rapidly with increasing depth. Almost everywhere the water that

comes from them from a depth more than a few feet below the bottoms of the neighboring creeks is likely to contain both salt and sulphur in moderate quantities.

Dug wells in the Maysville and Richmond formations usually procure sufficient water for a farm at depths ranging from 10 to 35 feet, the most common depths being 20 to 35 feet. Most of these wells are affected by the weather and many of them fail during a protracted drought.

Springs are numerous in both formations, but few of them are large. Many of the springs are perennial, and during a dry season maintain sufficient volume to furnish water for several families.

Water obtained from these formations above the level of the surface drainage is hard; that obtained below the level of the surface drainage is, as a rule, mineralized. Where the water emerges in some surface stream near the point where it enters the ground the underground circulation is so short that only a moderate quantity of mineral matter is dissolved. Where the dip of the rocks carries the water below the level of the neighboring surface stream the prolonged underground course allows the water to become highly charged with mineral matter, and if the rocks contain much organic matter such water will usually contain hydrogen sulphide, produced by the decomposition of the organic matter. The presence of hydrogen sulphide and large percentages of mineral matter in the water of wells that draw their supplies from depths below the levels of the surface drainage is thus explained. After water has been drawn from such wells for a considerable time the underground circulation may become more rapid and the amount of mineral matter and hydrogen sulphide may be lessened. The same result is brought about by the gradual removal of the amount of available mineral and organic matter along the underground channel. These highly mineralized waters have sometimes been regarded as residual sea water, but this theory is probably incorrect. In some places the Richmond formation contains magnesian limestones, and the water obtained from this phase of the rock contains considerably more magnesia than is usually present in hard waters.

WATER IN THE PANOLA FORMATION.

The limestones and shales of the Panola formation, as a rule, occupy areas of low relief, but in some localities they have been rather deeply dissected. The soils derived from the limestones are generally sufficiently porous to absorb considerable water, but those from the shales are commonly quite dense. Both topography and soils favor the occurrence of considerable underground water.

The limestones of the Panola are the principal water-bearing rocks. In some places, as in Fleming County, these rocks consist in part of

single beds of limestone alternating with beds of shale; but in other places, as in Clark, Madison, Oldham, and Trimble counties, the beds of limestone have an aggregate thickness of several feet. Even where the limestone beds are thin they generally yield considerable water. Where the limestone beds are thick the movement of the underground water is essentially the same as in the Lexington and Highbridge limestones. A few caverns have been reported in this formation, but they do not appear to be very numerous. One of the most interesting of these caverns is on Jeptha Knob, in Oldham County.

The shales of the Panola are locally traversed by numerous small joints that permit the entrance of considerable water; hence many shallow wells are successful and small springs are numerous.

Wells dug in the limestones of the Panola usually yield ample supplies of water for household or farm use. Drilled wells have also been successful, especially on the west side of the Jessamine dome in Oldham and Jefferson counties. The water is almost invariably encountered in the crevices of the limestone at its junction with the underlying shale.

The limestones of the Panola are highly magnesian, and the water which they contain is charged with magnesium in addition to the calcium and other salts that all limestone waters carry. Sulphur and salt are entirely lacking in these limestone waters, but zinc has been noted. The character of the water is shown by the analyses of the Anita Spring water and the water of the Royal Magnesian Spring.

The water from the shales of the Panola usually contains a large amount of mineral matter, especially Epsom salts and other sulphates. These waters are not extensively used within the area covered by this report, though there is a resort at Kiddville where an Epsom well obtains its water from this formation. At Crab Orchard, outside the area, the Epsom water has been used in the manufacture of Epsom salts, which have had an extensive sale. The mineral matter in these waters is believed to have been derived in part from the Ohio shale which lies above the limestones.

WATER IN THE OHIO SHALE.

In the Ohio shale water occurs chiefly in the joints, which are especially numerous near the surface and usually afford openings a fraction of an inch wide. The width of the joints diminishes downward, but they have been known to supply water at a depth slightly exceeding 50 feet. The bedding planes probably supply no water, except near the surface.

The soil of the Ohio shale is in most places sufficiently porous to allow considerable water to enter the underlying rock. Where the

formation occupies flat or moderately rolling areas it generally receives much of the water which is absorbed by the soil; where the surface is steep very little water enters the rock. On the mountain sides, however, where the sandstones of the Waverly shale overlie the Ohio, some of the water that comes from these sandstones enters the joints of the shale in its passage down the slope.

Wells in the Ohio shale are uniformly successful, the supplies of water being obtained at depths less than 50 feet. Where the formation is exposed many drilled wells have obtained sufficient water for the use of one or more families. Springs are numerous and some of them have been utilized as health resorts.

The water derived from the Ohio shale is highly mineralized, sulphur, alum, and chalybeate waters being especially characteristic types. Springs of Epsom and salt waters also occur.

WATER IN THE WAVERLY SHALE.

The shaly layers of the Waverly shale, which occupy the almost perpendicular sides of the mountains, furnish practically no water; but numerous springs of soft water that occur on the mountain side derive their supplies from the sandstone layers and shallow wells in the areas where the sandstones are exposed at the surface yield an abundance of water, although the rock is, as a rule, rather firmly cemented.

WATER IN THE ALLUVIUM.

Water occurs in the alluvium as in sands and gravels. The deposit is in most places sufficiently coarse to yield an abundance of water, but at one locality in northern Boone County the water-bearing sands are so fine that it is practically impossible to keep them from clogging the pumps.

The water in the alluvium is derived in part directly from rainfall and in part from springs and surface streams, although the rainfall probably furnishes the greater part. Each surface stream which emerges from the upland contributes to the water supply of the alluvium, unless its channel is lined with clay, which prevents the escape of the water, and some of the smaller streams lose a large part of their water in this way. Springs which emerge from the upland formations, either above or below the surface of the alluvium, also contribute to its water supply.

Under normal conditions the water table (see p. 39) of the alluvium slopes toward the main stream, and the water moves toward the stream to emerge in springs and in seeps along the channel. When the river rises the slope of the water table near its channel may be reversed, and the movement of the water may be from the river into the alluvium. This reversal of the normal movement is only temporary,

as the supply of water which the alluvium receives from the rainfall and from other sources soon raises the water table and reestablishes its normal slope toward the river. When a well near the river bank is pumped rapidly the slope of the water surface between the well and the river may be reversed so that the well draws some water from the river. This reversal of the slope of the water surface is due to the formation of a cone-shaped depression of the water table in the vicinity of the well. After the pumping ceases the water table rises and the ground water resumes its normal movement toward the river. The effect of the entrance of river water into the gravel along Ohio River has been noted at several points. Its presence may usually be detected in analyses by the small amount of mineral matter obtained in water near the river. The difference is shown by the analyses of the water from the wells of the Augusta steam laundry and the Augusta electric-light plant (p. 212). The steam laundry well is within about 10 rods of the river, and the well of the electric-light plant is several blocks distant. The difference is also illustrated by the behavior of the water in steam boilers. The water from the laundry well causes no scale, but the water from the well of the electric-light plant produces a large amount of scale, even after it has been passed through a heater which removes much of the mineral matter.

The quality of water in the alluvium varies greatly in different localities, and it may be expected to vary at any point as the conditions which govern the source of supply at that point change. The water that falls upon the alluvium percolates downward through the sand and gravel, dissolving lime and other materials which make it slightly hard. Water that is derived from the upland streams enters the gravel bearing whatever materials it has in solution. In the Blue Grass region the streams flow over formations that contain much limestone, and the water naturally carries a considerable amount of material dissolved from these calcareous rocks. The springs emerging from the formations through which the river valley is excavated contribute water carrying mineral matter that has been dissolved from these formations, and springs from different formations or even from different parts of the same formation may yield water differing greatly in quality. An example of the effect of spring water on the composition of the ground water of the alluvium was noted at South Ripley. At this locality Ohio River has cut nearly to the base of the Eden shale, and this formation or the underlying Winchester limestone probably supplies the salt water which gives the ground water in the alluvium at South Ripley a brackish taste.

AMOUNT OF UNDERGROUND WATER.

MODIFYING FACTORS.

RAINFALL.

The amount of underground water is influenced by several important factors, among which may be mentioned the quantity and character of the rainfall, the nature of the topography, the presence or absence of vegetation, and the character, condition, and thickness of the residual soil mantle.

Adequate rainfall is essential to abundance of ground water, but even when the rainfall is heavy the amount of water that enters the ground is greatly influenced by the rate of precipitation. Obviously, the conditions most favorable for absorption of water by the ground are slow precipitation and high temperature. The slow precipitation permits the water to enter the ground, and the high temperature facilitates its downward percolation. With decrease in temperature or increase in the rate of precipitation the percentage of rainfall that is absorbed is decreased and the amount of run-off is increased. If the precipitation takes the form of snow and falls upon a warm earth, its gradual melting may afford especially favorable conditions for the absorption of water; when the snow melts rapidly the amount of water that is absorbed is usually small.

The annual rainfall in the Blue Grass region varies from 40 to 50 inches, the precipitation being greatest in the southwestern part of the region and diminishing gradually toward the northeast corner of the State. A map prepared by Alfred J. Henry[a] shows an annual precipitation of 45 to 50 inches in the southern part of the area and of 40 to 45 inches in the northern part. The line on the map (fig. 4) separating these two belts of unequal rainfall crosses the counties bordering Ohio River in a northeastward direction until it reaches the latitude of Frankfort, and then bears eastward, passing north of Frankfort, to the east side of Licking River, where it turns to the southeast and extends beyond the southern boundary of the region. Lexington and Cincinnati, with mean annual rainfall of 44.38 and 39.87 inches, respectively, typify the conditions prevalent throughout the greater part of these two divisions. These figures represent the average rainfall as deduced from observations carried on over a number of years, but the actual precipitation for a single year may vary widely from the mean. An inspection of the following table (No. 4) shows that in the ten years from 1897 to 1906 the departure from the normal has exceeded 10 inches five times at Lexington and three times at Cincinnati. The maximum departure from the normal for any part of the area was 20.62 inches at Cincinnati in 1901. The

[a] Chart 12, U. S. Weather Bureau.

maximum departure at Lexington was 16.66 inches in 1904. Both of these departures were below the normal and mark periods of drought in their respective sections. The rainfall for the two years of drought

FIGURE 4.—Map showing average rainfall in eastern part of United States, in inches.

and for the two intervening years is given in Table 5. These droughts were not the result of the annual variation from the normal, but were caused by the continuation of a period of marked deficiency in

rainfall through three or four consecutive months. The drought of 1901, according to the figures given in Table 5, was most severe locally, but did not cover so wide an area as that of 1904. It was confined to a narrow strip along Ohio River and lasted from August to November. The drought of 1904 extended over much of the upland and was most marked in the last part of November and early part of December. It began as early as August in some parts of the area, and October was the driest month ever recorded in the region.

TABLE 4.—*Annual precipitation, in inches, and departure from the normal for four stations of the United States Weather Bureau, 1896–1906.*

Year.	Lexington.		Cincinnati.		Frankfort.		Shelbyville.	
	Rainfall.	Departure from normal.	Rainfall.	Departure from normal.	Rainfall.	Departure from normal.	Rainfall.	Departure from normal.
1896	43.29	− 1.67	34.48	.....	46.73	.....	46.54	− 0.15
1897	49.19	+ 2.30	43.89	+ 4.00	42.88	− 2.40	48.58	+ 3.00
1898	59.41	+14.67	38.97	− 0.90	.....	.....	52.73	+ 7.84
1899	40.24	− 2.76	34.69	− 4.94	.....	.....	41.14	− 3.73
1900	33.67	−10.58	27.79	−11.20	36.38	− 7.01	48.23	+ 2.12
1901	30.31	−13.29	17.99	−20.62	.....	.....	34.78	−10.42
1902	36.10	− 8.28	37.30	− 2.57	43.01	+ 1.38	38.35	− 6.12
1903	30.70	−13.68	34.69	− 5.15	38.42	− 3.71	38.46	− 5.84
1904	28.72	−16.66	29.54	−10.33	32.55	−10.65	32.18	−11.54
1905	44.17	− 0.21	38.69	− 1.18	46.91	+ 5.84	.....	.....
1906	42.59	− 1.79	40.83	+ 0.96	52.39	+11.32	51.64	+ 7.35

TABLE 5.—*Monthly precipitation, in inches, and departure from the normal at Lexington and Cincinnati, from 1901 to 1905.*

[Compiled from the reports of the U. S. Weather Bureau.]

Year.	Station.	January.		February.		March.		April.	
		Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.
1901	Cincinnati	0.87	−2.15	1.35	−2.17	2.01	−1.60	1.93	−0.95
	Lexington	1.49	−2.16	0.62	−2.73	2.23	−2.78	4.52	+1.14
1902	Cincinnati	2.10	−1.36	0.38	−3.31	1.47	−1.83	2.87	−0.33
	Lexington	4.77	+0.95	0.90	−2.80	2.92	−1.98	1.27	−2.45
1903	Cincinnati	2.05	−1.41	5.76	+2.09	4.97	+1.67	3.49	+0.29
	Lexington	1.68	−2.14	6.16	+2.46	3.24	−1.66	3.29	−0.43
1904	Cincinnati	2.66	−0.80	2.66	−1.03	8.17	+4.87	2.28	−0.92
	Lexington	1.92	−2.90	2.38	−1.32	4.75	−0.15	3.08	−0.64
1905	Cincinnati	1.80	−1.66	1.76	−1.93	2.46	−0.84	3.14	−0.06
	Lexington	2.04	−1.78	1.13	−2.57	5.87	+0.97	2.87	−0.85

TABLE 5.—*Monthly precipitation, in inches, and departure from the normal at Lexington and Cincinnati, from 1901 to 1905*—Continued.

Year.	Station.	May.		June.		July.		August.	
		Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.
1901	Cincinnati	1.62	−1.70	2.27	−1.69	1.44	−2.05	0.88	−2.66
	Lexington	2.66	−1.15	3.70	−0.50	2.61	−1.57	3.74	−0.35
1902	Cincinnati	5.54	+2.13	5.25	+0.85	3.47	+0.09	0.65	−3.07
	Lexington	2.43	−1.06	5.19	+0.94	2.33	−2.77	1.89	−1.63
1903	Cincinnati	3.83	+0.42	3.27	−1.13	2.31	−1.07	2.75	−0.97
	Lexington	1.75	−1.74	2.71	−1.54	2.62	−2.48	1.49	−2.03
1904	Cincinnati	3.70	+0.29	2.60	−1.80	0.80	−2.58	0.41	−3.31
	Lexington	2.60	−0.89	2.51	−1.74	3.13	−1.97	2.44	−1.08
1905	Cincinnati	9.52	+6.11	2.36	−2.04	1.04	−2.34	4.66	+0.94
	Lexington	5.54	+2.05	3.31	−0.94	4.94	−0.16	4.11	+0.59

Year.	Station.	September.		October.		November.		December.		Total.	
		Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.	Precipitation.	Departure from normal.
1901	Cincinnati	0.92	−1.43	0.59	−1.68	0.74	−2.59	3.37	+0.41	17.99	−20.62
	Lexington	2.18	−0.41	1.33	−0.78	1.73	−1.05	3.50	+0.40	30.31	−13.29
1902	Cincinnati	4.26	+1.84	2.77	+0.33	3.29	−0.01	5.25	+2.10	37.30	− 2.57
	Lexington	2.60	+0.06	2.11	−0.11	3.09	−0.63	6.60	+3.20	36.10	− 8.28
1903	Cincinnati	1.78	−0.64	1.31	−1.13	1.45	−1.85	1.72	−1.43	34.69	− 5.15
	Lexington	0.81	−1.73	2.12	−0.10	2.84	−0.88	1.99	−1.41	30.70	−13.68
1904	Cincinnati	1.28	−1.14	0.89	−1.55	0.34	−2.96	3.75	+0.60	29.54	−10.33
	Lexington	1.71	−0.83	0.57	−1.68	0.53	−3.19	3.10	−0.30	28.72	−16.66
1905	Cincinnati	1.54	−0.88	4.85	+2.41	2.75	−0.55	2.81	−0.34	38.69	− 1.18
	Lexington	3.20	+0.66	3.45	+1.23	3.58	−0.14	4.13	+0.73	44.17	− 0.21

Deficient precipitation lessens the quantity of water supplied by springs and shallow wells, but does not affect the supplies from deep wells. The effect of low rainfall is especially noticeable in the autumn months, when the precipitation is normally small. The time required for deficiency of rainfall to affect the amount of ground water varies with the quantity of water in the ground at the beginning of the drought, and the effect in different parts of the area varies with the nature of the materials in which the water is stored. In general, it may be said that a drought of two months usually causes a marked diminution in the amount of ground water; and if it continues for three or four months, the water supplies of the area are noticeably depleted.

When the amount of precipitation is much above the normal, the soil becomes saturated and the excess runs off over the surface. As the surface of the Blue Grass region is rolling, this excess moisture escapes readily.

During the spring and summer months much of the rainfall comes in the form of thunder showers. As a rule, these add comparatively little to the underground water supply, because the rapid precipitation favors run-off rather than absorption. In some parts of the area, however, open sinks abound, and in these localities a considerable part of the water falling during thunderstorms may enter the underground channels directly. The frequency of thunderstorms in the Blue Grass region is shown by the fact that in the ten years from 1895 to 1904 the Lexington station reported an average of 21 thundershowers for the three months from June 1 to August 31. Such storms also occur during other parts of the year, but less frequently.

TOPOGRAPHY.

Many investigators have assumed that, aside from its effect on the form of the water table, topography bears no relation to underground-water problems; but in reality the influence of topography on the amount of underground water is so marked that it is often possible to determine with considerable accuracy, from a study of the character of the surface of an area only, whether wells in a given locality are likely to have large or small yields.

A much greater amount of water is absorbed where the surface is level than where it is uneven, the level surface favoring absorption because the water flows off more slowly, and thus remains for a longer time in contact with the soil; a rolling surface favors rapid run-off. The influence of sink-hole topography on the quantity of ground water is especially noticeable, for while this topography is in itself an indication of the presence of underground streams, it also favors the absorption of large amounts of water.

The character of the topography also affects the thickness of the residual materials, for in many places on the rolling areas much of the decomposed rock has been removed by erosion, and wherever the thickness of the soil is reduced its storage capacity is lessened.

SOILS.

The permeability of soil depends largely upon its texture, a coarse-grained soil being, as a rule, much more permeable than a fine-grained. The capacity of the soil to retain moisture also depends upon its texture, the storage capacity of the finer soils being much larger than that of the coarser. The water which enters coarse sand passes through it rapidly, because of the large spaces between the grains; but that which is absorbed by clay is held by the capillary attraction of the small passages.

Although a coarse sand will readily absorb a large amount of water, it will retain only about 15 per cent of its volume; while a clay, which absorbs water more slowly, will retain more than 40 per cent.

By referring to Table 3 (p. 36) it will be seen that the soils of the Blue Grass region are very fine grained and hence have a large capacity for storing moisture. Determinations made by King [a] of the per cent of pore space and the approximate effective diameter of soil particles are given in the following table:

TABLE 6.—*Approximate effective diameter of soil particles.*

Type of soil.	Locality.	Depth of material.	Percentage of pore space.	Approximate effective diameter of soil grains.
				Millimeter.
Prairie loam	Oasis, Wis.	Surface	38.83	0.03035
Do	do	Second-foot	34.64	.04777
Clayey loam	Drummond, Wis.	Surface	44.87	.02206
Do	do	Second-foot	44.15	.02197
Heavy clay	Ashland, Wis.	Surface	45.32	.01402
Do	do	6–18 inches	44.15	.01111
Sandy soil	Minong, Wis.	Surface	34.49	.02619
Do	do	6–12 inches	29.96	.0523

These soils are not precisely the same as those of the Blue Grass region, but the table is valuable because it shows the porosity of loam, clay, and sandy soils. Actual measurements of the amount of water in the soils at Lexington and Greendale, Ky., were made by the United States Bureau of Soils.[b] These measurements include the surface soil to a depth of 12 inches and were made daily from May 18 to July 31, 1895. The maximum amount of water in the soils was found to be slightly more than 21 per cent of the total weight. The general range was about 13 to 21 per cent, and the lower limit was about 10 per cent. As these measurements were made at a time when frequent rains insured saturation of the soil, the maximum probably represents nearly the full water capacity of the soil.

The percentage by weight is only about one-half as great as the percentage by volume; hence, if reduced to percentage by volume, the maximum amount of moisture would be about 42 per cent and the range about 20 per cent. An examination of the table shows that the percentage of pore space diminishes in the subsurface materials, so that the average porosity of the residual materials at Lexington and Greendale is probably somewhat less than would be indicated by the table. The amount of reduction might bring the maximum as low as 35 to 40 per cent.

No measurements of the amount of water in other soils have been made, but assuming a porosity approximately the same as that for the soil types given in the table above, the clay would have a pore space of about 40 to 45 per cent of its volume and the sandy

[a] King, F. H., Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1897–98, pp. 213–214.

[b] Soils and soil moisture: U. S. Dept. Agr., Bulls. 1, 2, and 3, May, June, and July, 1895.

loam of about 30 to 35 per cent of its volume. As the silt loam has more silt and less clay than loam, its amount of pore space would probably be somewhat smaller than was found in the soils at Lexington and Greendale. The silt loam is of small extent and is underlain by gravelly loam or fine sand. Its porosity is probably slightly greater than that of the sandy loam.

From the above estimates of porosity it appears that even if the amount of water absorbed equaled only three-fourths of the total pore space, the residual deposits of the Blue Grass region would still hold a high percentage of moisture. The fact has an important bearing on the available water supply of the region, for the Ordovician limestones are too dense to yield water, and the water supplied to the shallow wells and springs during dry weather must be derived from the residual materials.

The residual materials in the Blue Grass region range in thickness from a few inches up to about 30 feet, the most common thickness being 3 to 5 feet and the average probably less than 6 feet. From this mantle of decomposed rock the transition to the solid rock below is rather abrupt. The importance of the residual material to the water supply does not depend upon its yielding water directly to wells, for this it does in but few places. Its real function is to store the rainfall and deliver it gradually to the underground channels. If the rocks of the Blue Grass region were laid bare the water from each rainfall would either enter the cracks at once or flow off over the surface at a rate determined by the slope, and in a comparatively short time all the water would have escaped, leaving the surface dry except where small pools were formed in depressions. Under such conditions springs would flow only a short time after each rain, because the rocks of the Ordovician formations have little or no storage capacity for moisture. The capacity of the residual soil to absorb moisture has already been mentioned. The small thickness of the residual mantle, however, prevents the storage of large quantities of water. As the porosity and thickness of the soil vary with the character of the rock from which it is derived, the water capacity of the soils of the different formations or of different parts of the same formation varies widely.

AMOUNT OF WATER IN THE EARTH'S CRUST.

Several attempts have been made to estimate the total amount of water in the earth's crust, but none of the results are universally accepted. To reach a conclusion it is necessary to estimate the average thickness of the various kinds of rock which compose the outer 6 miles of the earth and to compute the average amount of water contained in each kind of rock. The results obtained can not

be applied to any particular region, for they represent only the average condition for the whole earth, and as the results are not locally applicable their practical value is small.

The discussion has had, however, a practical bearing, in that it has called attention to the erroneous belief that an abundance of water can be obtained anywhere by drilling deep enough. In many places it has been found that the amount of water diminishes with increase of depth, and probably in nearly all places the amount of water below the first 2,000 or 3,000 feet is very small.

The quantitative estimates of the amount of water in the earth's crust vary from one-hundredth to one-half of the volume of the ocean. The smallest of these estimates was made by Fuller.[a] This estimate may be stated in another way by saying that the one-hundredth of the volume of the ocean means sufficient water to cover the entire surface of the earth to a depth of nearly 100 feet.

ARTESIAN WATER.

GENERAL PRINCIPLES.

The term "artesian" is derived from the name of a town in France, Artois, where the first important flowing wells were sunk. In this country the term has been used in so many different ways that it is often impossible to say just what particular kind of a well is meant. Some authors use artesian to designate only wells that flow; others apply it to any well in which the water is under hydrostatic pressure, so that it will rise above the level at which it is encountered; still others use the term to designate any deep well.

The desirability of securing uniformity of usage for the term "artesian" led Fuller to attempt to give it a precise meaning, and he proposed the following definitions:[b]

The artesian principle (which may be considered as identical with what is often known as the hydrostatic principle) is the principle in virtue of which water confined in the materials of the earth's crust tends to rise to the level of the water surface at the highest point from which pressure is transmitted. Gas as an agent in causing the water to rise is expressly excluded from the definition.

Artesian pressure is the pressure exhibited by water confined in the earth's crust at a level lower than its static head.

Artesian water is that portion of the underground water which is under artesian pressure and will rise if encountered by a well or other passage affording an outlet.

[a] Fuller, M. L., Total amount of free water in the earth's crust: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 59–72.

[b] Fuller, M. L., The significance of the term "artesian:" Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 14–15.

An artesian system is any combination of geologic structures—such as basins, planes, joints, faults—in which waters are confined under artesian pressure.

An artesian basin is a basin of porous bedded rock in which, as a result of synclinal structure, the water is confined under artesian pressure.

An artesian slope is a monoclinal slope of bedded rocks in which water is confined beneath relatively impervious covers owing to the obstruction of its downward passage by the pinching out of the porous beds, by their change from a pervious to an impervious character, by internal friction, or by dikes or other obstructions.

An artesian area is an area underlain by water under artesian pressure.

An artesian well is any well in which the water, when encountered, rises under artesian pressure.

The conditions commonly producing artesian wells are:

1. A porous bed or an open plane or channel to permit the entrance and passage of water.
2. An impervious cap to prevent the upward escape of the water.
3. An inclination of the water-bearing bed or passage.
4. A suitable exposure of the water-bearing beds or passages above the level of the surface at the well to permit the entrance of water.
5. An adequate rainfall to furnish the water.
6. An absence of openings which will permit the ready escape of water at a level below the well.

It was formerly believed that an impervious bed below the water-bearing horizon was an essential condition, but such a bed is not everywhere necessary because the rocks below may be saturated with water. Under certain conditions, also, the impervious bed above the water horizon may be dispensed with, for the interlocking grains in the layer of sands above the water may offer more resistance to its upward movement than is offered by the well. Even a porous bed may not be necessary to furnish artesian conditions, for artesian wells may be obtained where the water is in joints, solution channels, bedding planes, or other open passages. The inclination of the water-bearing beds may not everywhere be necessary, for the pressure may be supplied by the entrance of the water at a level above that at which it is encountered and by its downward passage through joints or other openings which cross the beds.

ARTESIAN WELLS IN THE BLUE GRASS REGION.

Flowing wells are not common in the Blue Grass region, but artesian wells—wells in which the water is under artesian pressure—are found in many parts of the area. The wells which encounter the

mineral water of the limestones are practically all artesian, and in a few localities where the wells are located in stream valleys the mineral water rises above the surface. Flowing wells of this class are found near Lexington, in Fayette County, near Harrodsburg, in Mercer County, and near Smitsonville, in Harrison County. The amount of water yielded by all these wells is small and the water is highly mineralized, being sulphureted and often brackish. The pressure of the escaping hydrogen sulphide gas in these waters may aid in producing the flow, the gas acting in the same manner as air which is forced into a well when an air-lift pump is used, but it is improbable that the gas pressure is sufficient to appreciably affect the height to which the water will rise. It is probable that the water in these wells does not enter at the outcrop of the beds under which it is moving, but finds its way in at various points along the underground streams through joints which reach the surface. The high mineral content of the water indicates that it has had a long underground course.

The shallow water in the limestone areas may be under artesian pressure wherever the underground channels are partly or wholly obstructed below the well, and if the water enters at a point higher than the surface at the well a flow may be obtained. No flows of this kind have been observed in the region.

The region is without large synclinal folds, and therefore contains no artesian basins. The flowing wells in the valleys of the large streams appear to belong to a structure intermediate between an artesian slope and an artesian basin. The rock in which this water occurs—the St. Peter sandstone—has been called both a sandstone and a siliceous limestone. It appears probable that some layers of this rock are very sandy while others are highly calcareous, but as the formation is known in this region only from well records its character is not easy to determine. It transmits water with a facility that suggests that it is either an open sandstone or a very porous limestone.

The effective head of the water in the St. Peter is 580 feet above sea level at the Murray well in Frankfort and 590 feet in the valley of Ohio River near Cincinnati. Flowing wells that reach this formation are located at Covington, Newport, Latonia, Frankfort, Boston, and the Old Crow distillery near the Woodford-Franklin County line. Flowing wells may be obtained in any part of the Ohio River channel where it borders the Blue Grass region and in the valleys of the principal tributaries of the Ohio where they have cut below about 590 feet above sea level. The flowing-well area would therefore include practically all of the gorge of Kentucky River within the Blue Grass region and the channel of Licking River for some distance above Falmouth, as well as the lower parts of some of the smaller valleys tributary to

these streams. Flowing wells may also be obtained in the lower parts of the small valleys tributary to Ohio River.

The quality of the water from the St. Peter, which is shown by analysis No. 11, page 212, unfits it for domestic or industrial uses. The water has been used for cooling in distilleries, but it has been found to corrode the condensing pipes very rapidly, and their frequent renewal is necessary. It is highly esteemed as a medicinal water and has proved valuable where a strong salt-sulphur water is required. It is also a valuable water for stock. The well at Boston is located in a pasture where ordinary spring water is abundant, but the stock will, it is reported, drink only the salt-sulphur water. The water from the well at Frankfort has been used for drinking. Wells should not be located near dwellings, for the hydrogen sulphide has a very disagreeable odor and is injurious if breathed for any considerable period. It has also an injurious effect on metal and on varnished or painted woodwork. A well located at the Hemingray glass factory in Covington was plugged because the residents of the neighborhood objected to having their furniture and silverware damaged by the sulphurous gas.

The source of the pressure which causes the water of the St. Peter to flow is not definitely known. It has been suggested that the water enters from the upland and passes downward through joints and other open passages into the sandstone, but many facts render this explanation highly unlikely. The hypothesis that the Jessamine dome of central Kentucky might be the source of the pressure is also inadequate, as the mouths of the flowing wells are from 200 to 300 feet above the top of the St. Peter in the apex of the dome. A third and, according to present knowledge, the most reasonable explanation is that the water enters the sandstone in southern Wisconsin and northern Illinois and that the pressure is transmitted from those areas.

It has been rather generally supposed that the water of the St. Peter is sea water, which was stored in the rocks at the time of their deposition. Adherents of this theory explain the fact that the St. Peter water is less saline than sea water by assuming that the percentage of salt has been decreased by the addition of surface waters. Although this theory has certain points in its favor, it is believed that the long underground journey of the water through rocks more or less calcareous is quite sufficient to explain its present qualities.

RECOVERY OF UNDERGROUND WATER.

NATURAL RECOVERY.

Much of the water that sinks into the earth returns to the surface under the influence of gravity, capillarity, and by the action of plants. Sometimes one of these forces acts alone, but more often two of them

are combined, and under some conditions one of the forces may oppose another. Capillary action, though usually not apparent, is very important, because it brings much water to the surface, where it is returned to the atmosphere by evaporation, or within the reach of the roots of plants, where it is absorbed. The water taken from the soil by plants is built into their tissues or evaporated through their leaves. This last process is usually called transpiration. Here gravity acts against the upward movement of the water caused by capillarity. Gravity combines with capillarity to bring the water to the surface at the foot of a slope. Capillary action causes the water to move more rapidly through the pores of the unconsolidated materials where the movement is downward under the influence of gravitation, the relative importance of gravitation and capillarity depending entirely on the size of the pores through which the water moves. If these pores are small, gravitation is much less important than capillary action; if they are large, gravitation is the principal cause of the movement of the water. Where water comes to the surface through open crevices or caverns, the movement is due wholly to gravity, but the weight of a column of water in the crevice or channel may cause the water to move upward in some parts of its course.

The water which is brought to the surface under the influence of capillarity alone is distributed over such a large area that it is rapidly absorbed by the atmosphere. That which is taken up by plants is given to the atmosphere either directly by transpiration or by evaporation when the plant decays. These processes go on so gradually that most of the water which is removed by them passes off as vapor. This fact has usually caused the influence of plants and capillarity on the amount of underground water to be disregarded, but in many regions the amount which is removed by these agencies probably equals 40 to 50 per cent of all the water absorbed by the soil.

Water which comes to the surface under the influence of gravity or the combined influence of gravity and capillarity emerges either in the form of springs or seeps.

Seepage is supplied by water from the pores of the rock and not from definite channels. It occurs wherever the level of the water table (p. 39) rises above the surface, as along the margins of streams, or where the surface and underground drainage is defective. The seepage which occurs along the margin of the streams forms but a small part of the whole, for the water also enters the channels of the streams below the water level. In the Blue Grass region water may be seen seeping from the rocks along the banks of the Ohio and other streams or in the depressions where the surface is comparatively level and the underlying rock is impervious. Many seeps on the upland

are utilized for stock and sometimes for domestic purposes by digging a hole in which the water may collect.

The water which emerges at any point in sufficient volume to form a stream is called a spring. Springs are formed by water coming from underground streams or by the concentration of percolating water at one point. It is difficult to distinguish sharply between seeps and springs supplied by percolating water, for with variations in the amount of ground water the springs may diminish in volume until they become mere seeps, or the seepage may increase in volume until springs are formed. In such cases the name "intermittent spring" has been used, but this term is also applied to certain springs formed by underground streams.

In the Blue Grass region springs form a very important source of water for domestic and industrial uses, but they are especially important as sources of water for stock. They occur in all parts of the region and in all the geological formations, but large springs are numerous only in the Lexington and Highbridge limestones.

A hole excavated about a spring or seep is commonly called a pool. Pools are usually walled with rock or cement and serve as reservoirs for storing ground water. Some of the pools in the Blue Grass region are 10 feet or more in depth. On one side an opening is left through which the animals may enter the water, and the floor of the pool is made to slope from the entrance so that the animals may reach the water as its surface recedes during dry weather.

ARTIFICIAL RECOVERY.

WELLS.

The artificial recovery of underground water is accomplished by means of wells, which may be classified as dug, driven, bored, and drilled.

Wells excavated by pick and shovel or by blasting and removing solid rock are called "dug wells." A well of this type is especially adapted to rock formations whose water supply is scanty or is unevenly distributed, for it furnishes a large surface for the entrance of water and a correspondingly large storage capacity. Dug wells are easily constructed in materials which are sufficiently compact to prevent caving of the sides; in looser materials some sort of wall must be provided. In solid rock the work of excavation is greatly increased by the necessity for blasting. In the Ohio Valley the early wells were dug, some of them to a depth of 50 or 60 feet or even more. On the uplands most of the dug wells are 20 to 30 feet deep, though many are less than 20 feet and a few exceed 30 feet. A few wells were dug and blasted to a depth of 100 feet. Dug wells are

especially liable to pollution because it is difficult to entirely exclude impure surface water. The dug wells vary in diameter from 3 to 5 feet, but in some localities, where a large storage capacity is desired, some of the dug wells are 25 to 30 feet in diameter.

Many driven wells have been sunk in the sands and gravels along Ohio River, and a few have been sunk in similar materials in the gorge of Kentucky River. Such wells are adapted only to unconsolidated sands and gravels, and hence there are none on the uplands.

Bored wells are excavated with an auger and, like driven wells, are adapted only to loose materials. A few bored wells have been sunk in the gravels along Ohio River. As the well is deepened an iron pipe the size of the hole is driven into the bore to prevent the walls from caving. In some wells a strainer is placed in the lower end of the pipe; but in others the pipe is driven down to within 8 or 10 feet of the bottom of the hole and the water enters through the sand or gravel below the end of the pipe. This method of sinking wells is slow, and unless the well is cased to the bottom the lower part of the bore is apt to fill in a very short time.

Drilled wells are put down by machinery of various sorts. In the Blue Grass region two types of machinery have been used. In the Ohio Valley at Covington a few wells have been sunk by means of a rotating pipe with loose steel shot at the cutting end. This method gives a core of rock nearly as large as the inside diameter of the pipe and thus enables the driller to judge the nature of the materials. On the uplands the churn drill is used. This drill depends for its effectiveness on the impact of a heavy steel bit which is raised and dropped in the hole. The drills are operated by horse power or by steam or gasoline engines. They are especially adapted to such rocks as are found in the region.

The type known as the diamond drill, which uses diamonds set in the bottom of the pipe instead of the loose shot, is not used in the Blue Grass region.

In unconsolidated materials the jet process is often used. In this process a stream of water is forced into the hole to loosen and wash out the material. An iron casing is forced in as fast as the hole is excavated.

The cost of drilling wells in the Blue Grass region ranges from 50 cents to $2 a foot, depending upon the diameter of the well and the amount of competition between drillers, the average being about $1 a foot. Driven and bored wells also cost about $1 a foot, the range being from 75 cents to $2.50. The cost of dug wells can not be readily ascertained, because few have been sunk within the last thirty years and most of the old ones were excavated by day laborers.

WELL CASINGS.

Dug wells in unconsolidated materials are commonly walled with rock, which is rarely well cemented. Where the wells enter rock the casing is usually used above the rock, but in some places where the residual soil is thin no casing is used. The rock walls would be materially improved by cementing them firmly together and to the rock below, as this would exclude a large amount of surface water. In the Ohio River valley the wells which have been bored, driven, or drilled are all cased with iron pipe.

The drilled wells on the upland are also cased with iron pipe, which extends only to the solid rock. These wells might be rendered safer from pollution by taking greater precaution to make a water-tight joint between the casing and the rock. Where the soil is thin this could be done by digging down to the rock and cementing the casing to it, but where the loose material is several feet thick it would be more convenient and economical to use rubber washers, such as are used in oil wells.

Certain wells might be improved by casing off supplies of polluted surface water from underground streams near the surface; and some of the deep wells which have encountered both fresh and brackish waters could be improved by plugging the well below the supply of fresh water. In a few wells where water escapes through cracks or crevices above the point where the supply was encountered the head would be increased by extending the casing below the opening through which the water escapes.

METHODS OF RAISING WATER.

All artificial recovery of underground water except that by flowing wells requires the use of some method of raising the water to the surface. In some dug wells a bucket is used, the water being drawn up by a rope attached to a windlass. Rarely an old-fashioned well sweep is employed, or the bucket may be raised from the well by hand without the use of any apparatus.

Chain or valve pumps are used in many wells. The chain pump is held in high favor because a great part of the water which it raises falls back into the well and thus affords a certain amount of aeration for the water.

In the drilled, driven, and bored wells force pumps are commonly used. Hand power is the most usual method of pumping, but windmills or engines are used where large supplies are required. Windmills have not everywhere proved satisfactory, especially on the large stock farms, and many of them are being replaced by gasoline engines. Steam engines are used to pump water for industrial plants where a constant supply is needed. A few hot-air engines are also used for

raising water in the Blue Grass region, and under certain favorable conditions "air lifts" have been installed.

COLLECTION AND STORAGE OF RAIN WATER.

CISTERNS.

Rain water is collected and stored in cisterns, ponds, and reservoirs. Where a small amount of water is needed it is usually collected from roofs and stored in cisterns. This method of procuring water for domestic use prevails throughout the upland areas of the Blue Grass region, and as cistern water is comparatively free from mineral matter it is usually considered more desirable than underground water.

Cisterns are ordinarily excavated to a depth of 10 to 20 feet, and where the materials are unconsolidated the cisterns are walled. In some parts of the Blue Grass region the wall is made of brick laid in cement, but the wall material most commonly used is stone. A stone wall, however, is satisfactory only where great care is taken to secure a perfect joint. Cisterns in rock are not walled, but the cement is applied to the rock, and if the rock contains water-bearing crevices the cement wall is apt to be too weak to withstand the hydrostatic pressure of the water outside the cistern. Under such circumstances the cistern should be walled just as if it were in unconsolidated materials. In some cisterns where the rock is exceptionally solid no cement is used, but the omission of the cement is hardly safe, because practically all rock admits some ground water into the cistern or allows some of the rain water to escape. Moreover, the rain water which is stored in uncemented cisterns gradually dissolves mineral matter from the rock and becomes hard.

Rain water collected after roofs and spouts have been thoroughly washed is practically free from inorganic matter. The desired washing is usually accomplished by allowing the first water which falls to escape through a waste valve. After the roof and pipes have been cleansed the waste valve is closed and the water is allowed to enter the cistern. This method is inconvenient, especially if the rainfall comes in the night, but it is desirable if the cistern water is to be kept pure and wholesome. During dry weather objectionable material of various sorts, such as dust that may contain germs of dangerous disease, leaves, or twigs, lodges on the roof or in the eaves troughs. Eaves troughs especially need constant attention, for they are frequently the nesting places of birds. Roofs should be kept painted to prevent the growth of moss and the accumulation of filth in the cracks.

Small filters are much used to purify the water before it enters the cistern, but their efficiency has frequently been overestimated.

Filters such as those here described may be used to remove some of the suspended matter which may have been derived from unclean roofs or water spouts, but they can not be depended upon to free the water from the organic matter which is apt to cause disease. The filter in most common use consists of a tin cylinder, 2 to 3 feet high and 18 to 24 inches in diameter, partly filled with alternating layers of charcoal and sand or with charcoal alone. Above this material is a screen which catches the leaves and fragments of wood that may be washed from the roof. Filters of this type are valuable only when they are kept clean and the filtering materials are renewed frequently. A filter of another type is excavated in the ground and walled like a cistern. The filter is made large enough to hold the water from a single storm and is connected with the cistern by a passage placed some distance above the bottom of the filter. The sediment collects below the level of the connecting passage and may be removed through a manhole at the top of the filter chamber. The filtering materials are so arranged that all the water entering the cistern must pass through them. Like the materials used in other filters they should be frequently renewed or they will become filled with foreign matter and their efficiency will be reduced. These large filters are more expensive than the others, but when properly constructed and cared for they are much more effective.

RESERVOIRS.

Reservoirs built to impound surface waters are numerous throughout the upland areas of the Blue Grass region. These reservoirs furnish water of good quality, both for city supplies and for farm use. As a rule the water is not highly mineralized, but it is likely to be turbid, especially where the catchment area is cultivated. In selecting a site for a reservoir it is best to choose some place where the area of the water surface will be reduced to a minimum, as the smaller the area the smaller the loss by evaporation. The best location is in a comparatively narrow valley with a steep gradient, which will permit the construction of a deep and narrow reservoir. In some such places, however, the rock beneath the selected site is found to be so badly fissured that it would be impossible to prevent leakage. Under such conditions another location must be sought. In the country districts these artificial reservoirs, or ponds form a very important source of water for stock.

For city supplies it is often necessary to build more than one reservoir, and such reservoirs may be arranged one above another on the same stream. This arrangement has three distinct advantages: It allows the collection of a supply of water during wet weather amply sufficient to last through a drought; in its passage from one reservoir to another the water receives some aeration; and the upper

reservoir catches most of the sediment and thus lowers the turbidity of the water at the point of intake in the lower reservoir.

MUNICIPAL WATER SUPPLIES.

SOURCES OF SUPPLY.

In the Blue Grass region both underground and surface waters are used for city supplies. The surface water is taken from rivers or small streams. The underground water is taken from streams in limestone, the supplies being obtained from wells which penetrate the channel of the stream or from springs at the point where the underground water reaches the surface.

SURFACE WATER.

The important sources of surface water for the region are Ohio River and its principal tributaries, or the small streams that enter these tributaries. Some of the small streams which are utilized for city supplies flow only a part of the year, and hence it is necessary to build storage reservoirs.

The surface water is ordinarily used without attempt to free it from the suspended matter present, though settling basins or filter plants have been constructed in a few places. Where more than one storage reservoir is available it is possible to utilize the uppermost as a settling basin, but the sediment may be so fine that much of it will reach the lower reservoir where the intake is located.

The sanitary character of the surface water varies greatly. Ohio River water is probably the most objectionable, because it receives the sewage of a number of cities above the region. The other rivers receive less sewage, but all of them flow through regions more or less densely populated. The water which is taken from small streams varies in character, according to the local conditions. One supply is from a stream which receives no drainage from farms, but all the other supplies are from streams which are to some extent polluted.

UNDERGROUND WATER.

In some localities the limitations imposed by nature make it impossible to procure enough underground water of a suitable quality for a city supply. Certain geologic formations of the Blue Grass region will not yield enough water at any one place for a city, while others contain water which is too highly mineralized for ordinary use. In fact, there are only two geologic formations—the Lexington limestone and the alluvium of the Ohio Valley—which will furnish enough underground water of suitable quality for a city, and neither can be relied upon to supply a large settlement. Water from the Lexington

limestone is fit for use only when it is obtained above the level of surface drainage, and enough water for a public supply can be obtained only in certain localities where underground drainage is extensively developed.

COMPARATIVE VALUE OF UNDERGROUND AND SURFACE SUPPLIES.

Although most people prefer underground water to surface water, the preference is seldom based upon a careful consideration of the relative merits of the two supplies. Water from the alluvial gravels of the Ohio Valley is little utilized as a source of supply, because of its proximity to the river, from which a large quantity of water may be easily obtained. The Lexington limestone supplies considerable water in some localities where surface water can not be obtained without constructing storage reservoirs. The water from the gravels is probably freer from pollution than surface water, because it undergoes filtration in its passage through the sand; but it contains considerable mineral matter, which must be removed before it is suitable for some industrial uses. The surface water is often polluted by sewage and surface drainage, and hence its sanitary condition is doubtful. It also contains a large amount of suspended matter, which unfits it for certain purposes. The polluting substances and suspended matter may be removed from the surface water by filtration, and the dissolved mineral matter in the water from the gravel may be precipitated by the use of softening compounds. As it usually costs more to soften water than to filter it, the surface water may be regarded as more satisfactory for municipal and industrial purposes than the water from the gravels.

Wherever the Lexington limestone yields large supplies, the water is derived from streams flowing in caverns, and these underground streams do not differ from surface streams in any essential particular except that they are partially covered by a roof of limestone capped by a few feet of clay.

As the underground streams are partly covered, they probably receive less objectionable drainage than the surface streams. This is counterbalanced by the fact that the drainage basin of the surface stream is well known, and hence it is possible to discover sources of pollution. The courses of the underground streams and their tributaries are little known, and it is not often possible to protect them against pollution. There is, moreover, small chance for the water in the underground stream to be purified by natural means. Therefore the surface streams usually form a more desirable source of supply than the underground streams. The water from either source should, as a rule, be filtered before it can be regarded as safe.

For industrial uses the surface waters have a decided advantage over those from the limestone, because they contain much less mineral matter in solution. It is true that the underground waters from the Lexington limestone are well adapted to certain industries; but they would need to be softened before they could be utilized for all purposes.

POLLUTION OF UNDERGROUND WATER IN THE LEXINGTON LIMESTONE.

In the preparation of this section on the pollution of underground waters in the Lexington limestone an attempt has been made to avoid, as far as possible, all strictly scientific and technical discussions, such as the efficiency of natural purification of waters and the value of various artificial methods of purification. Because of a desire to make the discussion as useful as possible, stress is placed upon the simple methods of tracing underground streams and determining possible sources of pollution.

The shallow water from the Lexington limestone is used for city supplies, and is fairly satisfactory. Certain features of this aquifer, however, suggest the possibility of pollution. Though it is possible to state certain general facts bearing on the subject of pollution, it is necessary to deal with each individual case strictly on its merits. The most important generalization is that the water which flows in limestone channels is not completely purified by its passage through those channels. There is a popular idea that water is purified by passing a short distance underground, a belief based partly on the effect of sand or sandstone on the water that traverses them. In close-grained, water-bearing rocks the purification is in part mechanical and takes place because the openings between the sand grains are very small; in other words, in removing objectionable matter the sand acts much like a filter. But when water flows through channels in limestone there is no filtration, and probably but little natural purification. The flow of water in limestone channels may be compared with its movement through ordinary water mains, and the chances for purification are about equal in the two cases. As there is little chance for natural purification of limestone waters, it becomes desirable to prevent pollution, and this can best be accomplished after the source of the polluting matter and the methods by which it reaches the water are thoroughly understood.

Persons using underground water are apt to consider its appearance and temperature indications of purity, for it is generally believed that water which is clear and cold is pure. No such belief is warranted by the facts, for some of the most dangerously polluted waters are both clear and cold.

Certain waters will be rejected as unfit for use because of the occurrence in them of straw or other visible materials of organic origin, and the wisdom of such rejection is too apparent to need comment. The presence of suspended matter in water is often taken as an indication of the entrance of surface water through an open sink hole, but such conclusion also may be erroneous.

From an inspection of the accompanying diagrams it will be seen that the presence or absence of sediment can not be considered a safe

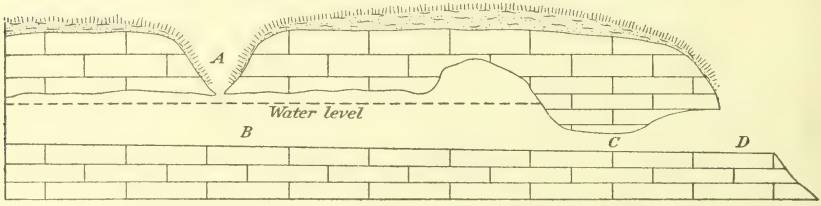


FIGURE 5.—Diagram of cavern showing how sediment may be deposited by the underground stream.

indication of the presence or absence of surface drainage. In the diagram (fig. 5) sediment-laden surface water entering at *A* may be so retarded in the chamber *B* that it deposits its suspended matter and passes through the constricted channel *C*, to emerge at *D* comparatively clear. In this case the water, though free from sediment, may contain considerable surface drainage in some other form. In figure 6, absolutely uncontaminated water in its passage round the fallen material from the closed sink *A* may obtain sediment and emerge at *B* so turbid as to cause the erroneous deduction that there is a direct connection with surface drainage.

The conditions represented by these two figures are transitory, for the chamber *B* (in fig. 5) will soon become partly filled with silt

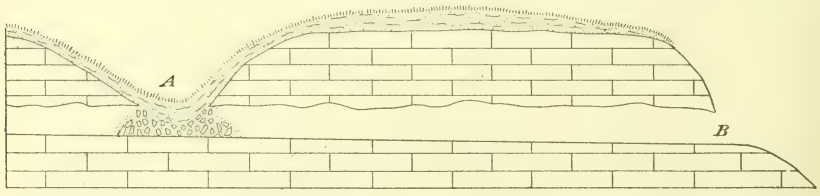


FIGURE 6.—Diagram of cavern showing how sediment may be obtained by the underground stream.

so that the water passing through the channel *C* will transport a considerable amount of sediment, while the gradual removal of material (in fig. 6) from the sink *A* will soon form an open hole. Such conditions may also be intermittent. In any case it is wise to refrain from drinking underground water which contains silt or clay, for while these materials in themselves are seldom injurious, they may indicate the presence of surface drainage which has received little or no natural purification. It must not be inferred that all

surface drainage is harmful, but it is well to bear in mind the possibilities of pollution by such drainage, and if any part of the surface drainage comes from a city or from dwellings, the water should be rejected.

It was formerly thought that a sanitary analysis of water was a reliable means of determining its potability, but this dependence upon chemical tests has little by little proved to be unsafe. For this reason a careful examination of the drainage basin to discover possible sources of pollution is recommended as more reliable than chemical or bacteriological examinations of the water. On this subject Dole [a] says:

> In brief summary it may be said that careful study by practical sanitarians of the chemical and bacteriological results of analyses, made not in one small section alone but all over the country, has failed to show that laboratory methods can be depended upon to detect pollution. On the other hand, sanitary survey strikes directly at the source of the evil—pollution—and affords definite bases for its removal or for protection against it.

The futility of sanitary analyses is illustrated by several examples given by Leighton.[b] One citation is of especial interest to inhabitants of the Blue Grass region, because the samples of water were taken from Kentucky River. In this case one sample of water was taken from Kentucky River at the intake of the Frankfort waterworks and another was taken from the same stream below the outlets of the city sewers. Both samples were taken on the same date and were judged by the standards usually employed in determining the potability of water. The conclusion reached by Leighton [c] is:

> The important feature * * * is that here is a water, or a dilute sewage, taken below the sewers of a city of 20,000 inhabitants showing practically the same, if not a better, condition, according to the interpretation standards, than another sample taken from the stream above the sewers.

This conclusion should not be taken as a condemnation of the city supply of Frankfort, for it merely shows the absurdity of relying upon sanitary analyses alone to determine the potability of water.

A satisfactory method of determining the potability of water is by means of a sanitary survey of the watershed from which the supply is drawn. Such survey, including as it does an examination of the entire watershed from which the supply is taken, makes practicable the determination of the sources of polluting matter and the adoption of measures to prevent contamination. Wherever streams flow through inhabited areas considerable objectionable matter is certain to enter the water and pollution can not be entirely pre-

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[a] Dole, R. B., Sanitary inspection versus sanitary analysis: Proc. Am. Pub. Health Assoc., vol. 31, pt. 1, 1905, p. 60.

[b] Leighton, M. O., The futility of a sanitary water analysis as a test of potability: Biological studies by the pupils of Wm. Thompson Sedgwick, Boston, 1906, pp. 36–53.

[c] Idem., p. 43.

vented. For this reason filtration is desirable; but the dangers from such pollution may be minimized by the use of ordinary care in the disposal of sewage and other waste materials.

Sanitary surveys of small surface streams may be made with considerable ease, but similar examinations of underground streams are attended with more or less difficulty. In order to ascertain the possible sources of pollution in an underground stream in limestone, it is first necessary to determine the location of the channels of the main stream and its tributaries. The course of the underground system may usually be inferred from the general slope of the surface and the position of sink holes. The location of minor tributaries is often so uncertain that it is necessary to go over the probable drainage basin with great care. In addition to examining the areas which from their surface slope are associated with the underground stream, it is advisable to survey the territory immediately adjoining them, because some underground streams pass beneath surface divides.

Besides considering the course of the underground stream it is also necessary to know how surface drainage reaches it. The water in the limestones flows in well-defined channels, to which it gains access either by seepage through the soil or directly through open sink holes. A portion of the water which enters the soil is almost certain to find its way to some underground stream, either directly or through some of the numerous crevices which traverse the limestone, and although it may receive some filtration and oxidation in its passage through the soil, reliance can not safely be placed upon this method of purification. The water which passes through the open sink holes carries with it much of the objectionable matter it may have obtained in its passage over the surface of the ground. Whatever purification this water undergoes takes place as the result of oxidation, bacterial action, etc., in the stream; and it is doubtful if the changes to which such objectionable matter is subjected are sufficient to render recently polluted water potable.

In the United States tracing the course of underground streams has received little attention, but in Europe, especially in the vicinity of Paris, much work of this sort has been done. A summary of investigations made by the city of Paris is presented by Dole [a] in Water-Supply Paper No. 160, and the reader is referred to that publication for a discussion of the results.

The common method of tracing underground streams in limestone is to introduce some substance into the underground channel at a convenient place and then to determine the presence or absence of the material thus added by examining samples of water from the underground stream at another place more or less removed from the

[a] Dole, R. B., Use of fluorescein in the study of underground waters: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 73–85.

point of initial introduction. Sometimes chemical salts are dissolved in water and introduced into the underground stream either directly through open holes or by seepage through the soil. Compounds which have been used are chlorides of sodium, calcium, or ammonium, potassium nitrate, and compounds of lithium or of iron. After the introduction of one of these substances chemical tests for its presence are made at frequent intervals in samples of water taken from the well or spring under study. For various reasons sodium chloride has been found to be most satisfactory and it is commonly used in preference to the other compounds. Successful experiments have also been made by coloring the water with solutions of potassium permanganate, fuchsine, Congo red, methylene blue, and fluorescein. Such substances as flour, starch, sawdust, leaves, oil, or cultures of bacteria may be suspended in the water and samples from the suspected spring or well water may be examined to determine their presence or absence. The choice of the material to be used depends largely on local conditions. Oil and other substances which float on the water are satisfactory only where there are no quiet reaches of water and no marked constrictions in the channel to delay their progress. In some streams they have proved satisfactory, while in others they have given negative results, and they are most useful in connection with other tests.

The use of fluorescein, one of the coal-tar products, is especially recommended, because this dye is not easily affected by the substances usually occurring in ground waters, and its color may be detected in very dilute solutions. According to Dole's abstract,[a] solutions containing 1 part of fluorescein to 10 billion parts of water will show, with the proper apparatus, the characteristic color of the fluorescein.

Salt or fluorescein may be placed in the underground stream and tests for their presence made at wells or springs at frequent intervals. In this way the time required for the substance to traverse the distance between the point of introduction and the places where samples are taken may be determined. If desired, the sampling may be continued until the water returns to its normal condition. It is usually best to take samples of water from as many sources as possible in order to determine the underground water conditions over an extended area. After the water has returned to its normal condition the testing materials may be introduced at some new locality and samples taken as before. This process can be repeated until the sources of the underground water are determined. It will usually be found that the stream receives tributaries from different directions in about the same manner as surface streams.

In choosing a spot for the introduction of the testing materials, preference is naturally given to places where there is free access to the underground channels, either through sink holes or through wells.

[a] Op. cit.

In such places the fluorescein solution may be poured into the stream. The most satisfactory method of introducing salt is in the form of a strong brine, which may be allowed to flow into the stream. Where open sink holes or wells are not available, the fluorescein or brine is usually placed in a shallow depression and allowed to enter the underground stream by percolation through the soil. In order to determine whether a cesspool drains into the underground stream, the identifying material is usually placed in the cesspool and tests are then made to determine its presence in the stream.

The use of salt in tracing underground drainage requires a certain amount of chemical knowledge and some skill in the use of chemical apparatus, because it is not usually practicable to introduce enough of the material for recognition except by chemical examination. Fortunately the test for salt is simple enough to be readily understood by those who are not specialists in the subject. It is made by determining the amount of chlorine present in the water both before and after the addition of salt (sodium chloride), and the procedure for this estimate is that in common use among water analysts, namely, titration with silver nitrate solution, using potassium chromate indicator. The method is outlined in detail by Leighton.[a]

The amount of salt necessary for any given test depends largely upon the mode of introduction into the underground channel and the volume of the stream. Where the salt can be poured into open sinks, it is possible to get satisfactory results with a smaller amount than where it is necessary to depend upon percolation through soil. In the examination of the big spring at Georgetown, Ky., from 2 to 4 barrels of salt were used with good results; and as this is one of the largest springs in the Blue Grass region, it appears probable that the maximum amount given above should be ample for the examination of most of the underground streams in the area. However, for such streams as those that emerge at the large spring at Spring Station or at Russell Cave, it might be necessary to use from 6 to 10 barrels in order to procure decisive results.

Fluorescein could doubtless be used in tracing the course of the underground streams in the limestones of the Blue Grass region, and because the test employed in detecting its presence in water is so simple its use is attended with fewer difficulties than the use of salt. It is introduced into the underground streams either directly through wells or open sink holes or by percolation through soil. In alkaline waters a strong solution of fluorescein gives a red color by transmitted light and appears green by reflected light. If the solution is very dilute, the red color is not detectible, but the green color is very powerful. An apparatus called a fluoroscope, described in Water-Supply Paper 160, has been devised for recognizing small

[a] Leighton, M. O., Field assay of water: Water-Supply Paper U. S. Geol. Survey No. 151, 1905,–50 pp. 49.

quantities of the dye in samples of water. This instrument is very simple, consisting merely of long, colorless glass tubes plugged at one end by stoppers blackened with plumbago. The tubes are filled with the samples of water, and the presence of fluorescein is demonstrated by a greenish tinge of the sample when it is viewed by reflected light.

Oil, fragments of wood, and sodium chloride were used in studying one of the underground streams of the Blue Grass region. The materials were put into the stream through an open sink about one-eighth of a mile from its point of emergence in a spring. The oil appeared at the spring in one hour, the chloride of sodium in seven hours, and the wood fragments had not appeared after a lapse of several days. Salt is satisfactory for use in streams having a daily flow of a few million gallons or less; but its introduction is impracticable in very large streams such as those found in some caverns.

Water from small channels in limestone may generally be considered safe provided care is taken to guard against local pollution; but the source of the water in the streams in large caverns should be sought. Whether an underground stream for a city supply is safe or not depends entirely on the local conditions. The first questions to be decided are the source and the direction of flow of the water. If the underground stream clearly does not receive polluted water, it may be regarded as a safe source of supply; but if the stream passes beneath or near the city, the intake should be located on the upstream side of the town. The importance of taking the supply from above the town is recognized when dealing with surface streams, but it is sometimes disregarded when the stream is beneath the surface. Not infrequently belief in the natural purification of underground water leads to carelessness in locating the intake. Occasionally the fact that there are several feet of solid limestone or beds of "soapstone" above the underground stream gives the impression that local drainage is excluded. Such idea is wholly erroneous, because the so-called solid limestone or the soapstone contains many cracks and crevices, which allow the surface water to enter the underground channel.

If water from limestone caverns is used, a sanitary survey is desirable to determine the course of the stream and the sources from which it obtains its supply. In a question of potability it is much better and far safer to make a practical inspection of the drainage area, as outlined in the preceding pages, than to place reliance upon a chemical analysis of the water.

The practice of putting rubbish, barnyard filth, etc., into sink holes should be abandoned. Still more reprehensible is the custom of running sewage into sink holes, thus converting the underground channels into natural sewers. This practice, by no means uncommon, is often defended by the claim that the water in limestone

channels beneath the city is unfit for drinking. The correctness of this claim can not be disputed, but there are persons ignorant of the danger who continue to use the underground water. Moreover, those living at some distance from the city may take water from the polluted stream.

NOTES ON CITY SUPPLIES.

The Covington water system, which is the largest in the Blue Grass region, takes its supply from Ohio River. The water is pumped to a settling reservoir on the upland. From the settling reservoir it passes to a storage reservoir and thence to the distributing reservoir. Considerable sediment collects in the settling basin. Ohio River water contains some inorganic matter in solution; but the amount is not sufficiently large to render the water unfit for industrial uses.

The Cynthiana water supply is taken from Licking River. The water is pumped to a reservoir and distributed under gravity pressure to the city. The sediment in the water could be readily removed by the use of a mechanical filter. The small amount of inorganic matter held in solution does not render the water objectionable for use in boilers.

The Danville water supply is drawn from Dix River, and is reported to be satisfactory. There is no great danger of pollution, and as the water is filtered, its sanitary condition is guarded.

The Falmouth water supply is taken from Licking River. The water is so turbid that it is not suitable for domestic uses; but it is drunk by stock and utilized in some industries.

Frankfort is the only city which takes its supply from Kentucky River. There are no large cities on the Kentucky above Frankfort, but considerable waste from distilleries is allowed to enter the river. The water of the Kentucky, like that of other streams in the region, is very muddy during a large part of the year, and could be improved by filtration.

The Maysville water supply is pumped from Ohio River. The reservoir is situated on the upland above the town, at an altitude sufficient to give a very strong pressure in the city. The quality of the water is much the same as that of the river above Covington and Newport.

The Newport Water Company uses Ohio River water. This water is very turbid and its sanitary quality during a large part of the year is doubtful. The water is pumped to a reservoir on the upland and distributed to the city by gravity.

Lancaster has constructed an impounding reservoir on a small stream. The watershed of this stream is not cultivated and is uninhabited. The water is pumped directly from this reservoir into the mains.

Lexington has a water supply which gives universal satisfaction. The water is impounded in three reservoirs, placed one above another on the same stream. The upper reservoirs serve as settling basins when the stream is high and the water turbid. Before being pumped into the mains the water is aerated and filtered. The water is used in nearly all of the manufacturing plants of the city.

The water supply of Paris is taken from a creek. A mechanical filter is used to remove sediment from the water. The supply is ample for the prospective needs of the city and should prove very satisfactory.

The Richmond Water Company takes its supply from a small stream which receives very little drainage of an objectionable character.

The water supply of Shelbyville is taken from Clear Creek. Unfortunately, the water is not always as clear as might be expected from the name of the source.

The supply for the city of Winchester is taken from two reservoirs constructed on a small stream. It is ample for all purposes.

The Lawrenceburg supply is taken from wells sunk in the Lexington limestone. The water is reported to be slightly hard, but it is satisfactory for use in boilers.

The Nicholasville supply was formerly taken from a reservoir on a small stream. It is now pumped from wells which are sunk at the edge of the reservoir, and these wells probably draw considerable water from the reservoir. This water is said to be slightly hard and to form a small amount of scale in boilers.

Georgetown is supplied with water from a large spring located on the west edge of the city. The water is moderately hard and forms some scale in boilers. The volume of the spring is always large, but it fluctuates greatly, rising rapidly after a rain and subsiding again in a short time. The water contains considerable sediment after a rain, and the character of the sediment suggests that surface drainage enters through open sinks.

The water supply of Berea College is derived from ten springs issuing from the sandstones of the mountains. Each spring is surrounded by a cement reservoir. The water is conveyed from these reservoirs to a 6-inch main, which conducts it to the college grounds. The combined flow of the ten springs is about 100 gallons per minute, and their altitude above the town gives a gravity pressure of 95 pounds per square inch. The water has been analyzed at the college and is reported to contain less mineral matter than water taken from cisterns. Springs like those that supply Berea College are numerous, and similar supplies could be installed in many of the towns near the mountains.

Table 7 gives the available information concerning the municipal water supplies of this region.

TABLE 7.—*Municipal water supplies of the Blue Grass region.*

SUPPLIES FROM RIVERS.

No.	City.	Owner.	Source.	From what distributed.	Capacity of reservoir or standpipe.	Elevation of reservoir or standpipe in feet.		How distributed.	Length of mains.	Number of taps.	Number of fire hydrants.	Number of people supplied.	Population of city in 1900.	Daily consumption.	Maximum capacity of pumps.	Domestic pressure.	Fire pressure.
						Above source of supply.	Above city.										
1	Covington, Central Covington, Latonia and Ft. Thomas.	City	Ohio River	Reservoirs	*Gallons.* +31,970,100 26,622,200 27,368,800	+353	250	Gravity	*Miles* +45	+6,436	....	45,000	a42,938 b4,185	*Gallons.* 2,823,432	*Gallons.*	*Lbs.* 100	*Lbs.* 100
2	Cynthiana	do	Licking River	Standpipe	315,000	.....	.....	do	7	400	75	2,500	3,257	.....	.....	100	100
3	Danville	do	Dix River	do	225,000	+500	164	do	11	385	112	1,800	4,285	350,000	2,000,000	70	70
4	Falmouth	do	Licking River	Reservoir	1,100,000	.....	.....	do	$\frac{3}{4}$	150	27	750	1,134	.....	.....	100	100
5	Frankfort	Frankfort Water Co.	Kentucky River	Reservoirs	4,000,000 4,000,000	+329	+390	do	15	1,250	130	10,000	9,487	2,000,000	8,000,000	120	120
6	Harrodsburg	Harrodsburg Water Co.	Salt River	Standpipe	289,000	+100	.....	do	8	300	84	.....	2,876	90,000	1,000,000	70	70
7	Maysville	Maysville Water Co.	Ohio River	Reservoirs	1,500,000 1,500,000	+400	365	do	14	1,000	82	8,000	6,423	600,000	2,500,000	150	150
8	Newport and Dayton, Bellvue	City	do	Reservoir	6,000,000	+330	+250	do	35	5,600	265	.....	.....	1,185,100 6,505,700	.....	.....	.....

SUPPLIES FROM SMALL STREAMS.

9	Lancaster	City	Springs and creek.	Reservoir	30,000,000	0	−100	Direct pressure.	4½	135	40	1,000	1,640	15,000	1,000,000	40	100
10	Lexington	Lexington Hydraulic and Manufacturing Co.	Creek	do	640,000,000			do	43½	+2,716	388	+25,000	26,369	1,700,000		45	100
11	Paris	Paris Water Co.	Hinkston Creek.	Standpipe	300,000	+ 40		Gravity and direct pressure.	9	725	108	3,750	4,603	500,000	2,500,000	50	100
12	Richmond	Water and Light Co.	Springs and creek.	do		+100	+ 50	do	6	525	90	3,000	4,653	150,000	2,000,000	−80	100
13	Shelbyville	Shelbyville Water and Light Co.	Creek	do	60,000			do	4		56	2,000	3,016	200,000	1,000,000	40	120
14	Winchester	Winchester Water Co.	do	do		+ 65		do	16	513	138	3,000	5,964	375,000		55	100

SUPPLIES FROM WELLS.

15	Lawrenceburg		4 wells	Standpipe		+100	+100	Gravity and direct pressure.	4	140	31	475	1,253	40,000	500,000	55	130
16	Nicholasville	Nicholasville Water Co.	do	do	150,000			do	4	150	50	750	2,393	7,000	500,000	50	75

SUPPLIES FROM SPRINGS.

17	Georgetown	Georgetown Water, Gas, and Electric Light Co.	Big spring					Direct pressure.		550	74	3,000	3,823	250,000	500,000	75	115
18	Berea	Berea College	Springs (10)	A reservoir at each spring.			+300	Gravity	6			1,200–1,500	762	30,000		95	95

[a] Covington.

[b] Other cities.

MINERAL WATERS OF THE BLUE GRASS REGION.

CHARACTER OF THE WATERS.

The underground waters of the Blue Grass region vary widely in composition, the amount of inorganic matter in water ranging from a few hundred to several thousand parts per million. Although the kind of mineral matter is determined by the character of the soil and rock through which the water has passed, certain mineral ions, such as calcium, magnesium, sodium, potassium, chlorine, and the carbonate and sulphate radicles, are common to most of the waters of the region. This is to be accounted for by the fact that the substances mentioned are to be found in the soils and rocks of all parts of the region and that they are all more or less soluble in the ground waters. Many of the waters, especially those from the Ordovician rocks, contain small quantities of some of the rarer elements, such as boron, strontium, lithium, and iodine.

The most common type of mineral water in the Blue Grass region is the alkaline water which contains carbonates of lime, magnesia, sodium, and potassium, together with other carbonates and sulphates. These waters are found in nearly all parts of the area and are commonly designated hard waters.

Hydrogen sulphide occurs in most of the deep waters of the Ordovician area and in some of the waters from the Ohio shale. In the waters of the Ordovician rocks the hydrogen sulphide is often accompanied by petroleum or asphaltic material, suggesting that it is derived from the decomposition of organic matter. The sulphuretted waters from the Ohio shale probably derive their hydrogen sulphide from the decomposition of the sulphide of iron, which is abundant in the shale.

Salt is a very common constituent in the deep-seated waters of the Blue Grass region and it also occurs in some of the waters from the Ohio shale. Its frequent association with hydrogen sulphide has led to the use of the term "salt-sulphur" for such waters as those from the St. Peter sandstone and some of the waters from the Highbridge and Lexington limestones. Besides the salt-sulphur waters, salt waters which are free from hydrogen sulphide also occur.

Some of the waters of the Silurian and Devonian formations contain magnesium sulphates and are known as epsom waters. Sodium carbonate (glauber salts) is also common in some of the waters from the Devonian and Silurian shales. Various other mineral substances are known to occur in the waters from the Ohio shale, the most prominent being the iron which occurs in the Chalybeate Springs. The iron appears in the springs in the form of the hydrous oxide,

which is probably formed by oxidation of the iron compounds present in the spring water.

The wells which penetrate the St. Peter sandstone obtain strong salt-sulphur water, known locally as "Blue Lick" water. The water is often used for medicinal purposes. The wells which are best known are located at Newport, Boston Station, and Frankfort. At Sanders a well which probably penetrated this formation procured a salt-sulphur water which is said to contain a notable quantity of lithia. This water is sold under the name of the Eagle Valley Lithia Water.

Water is being sold from a number of wells in the Lexington limestone, and, judging from the mode of occurrence and the analyses, there are many others which might supply marketable water. The best known mineral waters from wells in this formation are the Lexington Lithia water and the Renfro water. The former contains considerable lithia and the latter contains both lithia and sulphur.

One of the best known of the medicinal waters is the "Blue Lick" water which comes from the Lower Blue Lick Springs. This water has a large sale and has been known throughout the South for more than half a century. It also has a large sale in the northern half of the country. The composition of the water, as shown by the analyses, has not changed materially in the last fifty years.

Salt-sulphur water is obtained from the Upper Blue Lick Spring, the Big Bone Springs, the Sanders Sulphur Spring, Drennon Springs, and from many other springs in various parts of the region.

So remarkable is the general resemblance between the Blue Lick water and the water of the St. Peter sandstone that it has often been suggested that the Blue Lick water comes from the St. Peter. Aside from the fact that both are salt-sulphur waters, there is little reason to believe that they have the same origin. Their mode of occurrence suggests that the Blue Lick Springs may derive their water from either the Winchester or the Lexington limestone. In support of this idea it may be said that the Blue Lick water resembles somewhat the deep waters of these limestones, though the resemblance is due rather to such constituents as salt, sulphur, and other elements common to many of the Blue Grass waters rather than to the less common compounds, such as are mentioned in the chemical discussion (p. 207) under the head of Lower Blue Lick Springs. No evidence was noted that would suggest that a fault existed at the Blue Lick Springs, and in the absence of faulting it does not appear probable that the waters of the St. Peter sandstone would rise through the Lexington and Highbridge limestones which overlie the St. Peter.

Big Bone Springs supplies a strong salt-sulphur water which, as already stated, resembles the Blue Lick water. There were originally three springs at this locality. A well which was drilled at one of these springs is reported to have encountered salt-sulphur water at depths of 150 and 500 feet. This well now flows through a wooden pipe which rises 4 feet above the ground, and since it has been drilled one of the original springs has nearly ceased to flow. The water which is now being sold comes from this well. From the well logs (see report of Boone County, p. 163) it appears probable that the Big Bone Springs water originally came from the Lexington or Highbridge limestones, and these formations now supply the water which is obtained from the flowing well.

The limestone of the Maysville formation furnishes very little water of commercial value. At Buffington there are three springs, belonging to J. S. Haynes, which supply water for a small health resort, known as Keo-Me-Zu Springs. These springs are situated within a radius of 20 feet, but they present certain differences in composition. The only other locality where the Maysville formation is known to furnish water of commercial value is at Beechwood, Owen County. The Beechwood Spring—really a shallow well—furnishes water containing a large amount of magnesium, apparently in the form of magnesium sulphate.

The Silurian shales furnish mineral waters at Crab Orchard, just outside the area mapped, but they are not important within the Blue Grass region. They are the source of some mineral water in eastern Clark County, and possibly in some of the neighboring counties. The upper limestone beds of this series furnish an abundance of water in localities where they are not deeply buried beneath the Waverly shale. Some of the springs from the limestone of the Panola formation are being extensively used, the most prominent being the Anita and Royal-Magnesian springs. The waters of these springs are not sold as mineral waters, but they find a ready market as pure drinking waters. Other springs from this formation are known near the western margin of the area and at various points on the eastern side of regions in the vicinity of Waco and elsewhere.

The Ohio shale furnishes valuable mineral waters at various points in central Kentucky. Within the area mapped the most important localities are Linietta Springs, at Junction City, and Alum Springs, 4½ miles west of Junction City, Boyle County; Fox Springs, Fleming County; Dripping Springs, Garrard County; Kiddville and Oil Springs, Clark County. Outside the area mapped are some very important springs which have been included in this report—Estill Springs, Olympia Springs, and Crab Orchard Springs. These resorts were not visited by the writer. Both the occurrence and the character of the waters are fully described in several of the reports of the

Kentucky Geological Survey. The Olympia Springs were discussed by Linney in his report on the geology of Bath County, from which the following statement is taken:[a]

These springs are situated near the head of Mud Lick Creek, 2½ miles from the Chesapeake and Ohio Railroad, at Olympia station, and consist of a salt well, a salt-sulphur well, black-sulphur well, two chalybeate springs, and a well and a spring whose waters are alkaline saline. Some of these have been known and used nearly since the first settlers came to this part of the State. The geological position of these waters is the same which gives rise to the majority of mineral waters in the State. They arise from near the union of the rocks of the Corniferous limestone with the black slate. This is a horizon in which magnesian limestones, clay shales, salt, sulphide, carbonate and other forms of iron, and minute quantities of other minerals are found in close proximity. Water penetrating the rocks dissolves the mineral matters in various proportions, new combinations are formed, and thus originate these various mineral springs.

In his report on the geology of Lincoln County, Linney gives the following facts relating to the source of the Crab Orchard Springs and the Crab Orchard salts:[b]

In Lincoln County there are a large number of mineral springs. Some of these, situated in and near Crab Orchard, have old and extended reputations. These springs furnish several classes of water.

The black slate everywhere contains more or less of the sulphides of iron. These compounds, by their decomposition, furnish a variety of sulphur, and sulphur and chalybeate waters—among which salt-sulphur and black-sulphur are the most common.

The lower Subcarboniferous shales furnish some weak springs of chalybeate, but the best water of that kind issues from a layer in the Upper Silurian, which contain oxides of iron.

In the Crab Orchard shales are a number of springs and seeps which furnish magnesian waters. Weak alum waters are known at a few places, while salt water has been obtained in the county in boring wells for other purposes.

Crab Orchard salts is a name given to a peculiar variety of epsomite—Epsom salt or magnesian sulphate—which is manufactured from the Crab Orchard shales of the Upper Silurian in Lincoln and Garrard counties. They differ from the common type of other magnesian salts, so well known to commerce as a medicine, in containing a number of other ingredients which enhance their value.

This strip of country, in which these shales predominate, and the manufacture of these salts is conducted, is an irregular one, about 13 miles in length, and from a few hundred yards to 2 miles in breadth. They lie on a slope in the rocks to the southeast, and are from 16 to 40 feet in depth. Through all this line and thickness they are impregnated with the minerals which characterize the salts.

The origin of this deposit is an interesting question, worthy of investigation. That the shales and the minerals contained in them were thrown down from solution during the evaporation of the ocean water in shallow basins, raised above the sea level, is hardly to be accepted, as the differences in the shale and the interstratification of limestone would require other conditions for their formation. It seems more probable that the materials for the shales were swept in and deposited in protected places by currents, and that afterward these minerals, which had been contained in the magnesian layers of the Upper Silurian and Devonian series, were carried down this slope, and found in those shales the conditions for their deposition and preservation.

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[a] Linney, W. M., Reports on the geology of Bath and Fleming counties: Geol. Survey Kentucky, 1886, pp. 36, 37.

[b] Linney, W. M., Report on the geology of Lincoln County, Geol. Survey Kentucky, 1882, pp. 29–32.

A bulletin of the Kentucky Geological Survey, by A. F. Foerste, received after the preparation of the body of this report, discusses the mineral waters of the Ohio shale as follows:[a]

It has been stated that the table of contents of the waters from a mineral spring is but an index of the various geological strata through which its waters have passed and of the mineral bodies with which they have come in contact. In this sense, the Devonian black shales should be of special interest to the people of Kentucky, since a considerable part of the springs which are visited, more or less for their medicinal virtues, issue from the black shales. Among these may be mentioned the Fox Springs, 8 miles east of Flemingsburg, in Fleming County; the Olympian Springs, in the southeastern part of Bath County; the Oil Springs, about a mile northeast of Indian Fields, in the northeastern part of Clark County; the Estill Springs, about a mile north of Irvine, in Estill County; Hale's well, about 4 miles southeast of Stanford, in Lincoln County; the Linietta Springs, northwest of Junction City, in Boyle County; Alum Springs, 2 miles farther west, in Boyle County; the Sulphur Springs, 3 miles southeast of Lebanon, in Marion County; and numerous other springs, less known but with waters containing the same ingredients.

PRODUCTION OF MINERAL WATERS.

The total sales of mineral water from the Blue Grass region approximate $200,000 annually. Of this amount, about one-fourth is derived from the sale of table waters and the remainder from the sale of medicinal waters. Apart from the sales, considerable water is consumed at the springs where there are hotels.

COUNTY CONDITIONS.

ANDERSON COUNTY.

SURFACE FEATURES.

Anderson County is located near the western border of the Blue Grass region. Its western boundary is formed by Kentucky River, which here flows in a trench more than 400 feet below the upland and so narrow that the river occupies nearly the entire width of the gorge.

The surface of the upland near the Kentucky is broken by deep canyons where the tributary streams have cut into the limestone formations. A short distance back from the river the surface becomes gently rolling, exhibiting shallow valleys separated by rounded divides. Toward the western boundary the valleys are deeper and narrower and the areas of level upland are much smaller.

A narrow strip along the eastern edge of the county is drained by small streams tributary to the Kentucky within the county, and a small area in the northern part by streams that join the Kentucky in Franklin County. The central part of Anderson County is drained

[a] Foerste, A. F., The Silurian, Devonian, and Irving formations of east-central Kentucky: Bull. Kentucky Geol. Survey No. 7, 1906, p. 255.

by Salt River, which enters from the south, flows northward to a point a few miles southwest of Lawrenceburg, then takes a southwesterly course to Van Buren, where it leaves the county. This stream receives no large tributaries within the county except Crooked Creek, which flows along the western border of the county and joins the Salt near Van Buren. A small area in the southwestern part of the county is drained by two tributaries of Chaplin River—Beaver and Sulphur creeks.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials of Anderson County consist of yellow or red clays from 2 to 8 feet thick, the average thickness being probably less than 3 feet. These soils yield water in few localities to wells, but they store considerable quantities and supply it gradually to the crevices in the underlying rock. A deposit of sand containing pebbles of chert—the alluvium which has been transported from the hills to the southward and deposited wherever the gorge was wide enough to permit its accumulation—is found in narrow, discontinuous strips along Kentucky River. Such alluvial deposits supply water in abundance to springs and driven wells.

CONSOLIDATED MATERIALS.

The geologic formations appearing at the surface in Anderson County include the Highbridge limestone, which is exposed in the Kentucky River gorge; the Lexington limestone, which forms a part of the upper walls of the gorge and extends out a short distance on the upland, and which is also exposed in the valley of Salt River from the southern line of the county to the point where the river makes the bend toward the southwest; the Winchester limestone, which lies in narrow strips outside the areas of Lexington limestone and occupies a large area in the central part of the county; and the Eden shale. It is possible that rocks belonging to the Maysville formation may occur on some of the higher hilltops near the western boundary of the county, but no evidence of their presence has been obtained.

In areas where they appear at the surface the Highbridge, Lexington, and Winchester limestones furnish considerable hard water to springs and shallow wells. At depths varying from 50 to 100 feet, however, the Lexington and Highbridge yield salt and salt-sulphur water; and highly mineralized water, usually containing salt and sulphur, is also obtained from wells in the Winchester limestone which have been sunk below the level of the surface streams. The Eden shale usually occurs on the slopes or tops of hills and in such situations

that it furnishes only small quantities of water to springs and shallow wells; below depths of 30 to 35 feet it contains practically no water.

The St. Peter sandstone underlies the county and will furnish flowing wells in the gorge of Kentucky River and probably in the lower parts of some of its tributaries. The water from this horizon is, however, highly mineralized, and is in addition saturated with hydrogen sulphide gas.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

The water for city supplies and manufacturing in Anderson County is obtained from drilled or dug wells, cisterns, and springs.

Drilled wells are numerous in the eastern part of the county, especially near Tyrone, McBrayer, and Lawrenceburg, the city last named obtaining its supply from wells sunk in the Lexington limestone. The drilled wells vary in depth from 40 to 80 feet, although a few of them obtain water at 25 feet or less. Sulphur water is encountered at various depths, ranging from 25 to 30 feet in the valleys of some of the tributaries of Salt River to over 100 feet near Kentucky River.

Dug wells are found in all parts of the county, but they are more numerous in the western part. Few of them exceed 30 feet in depth, and they are apt to fail in times of drought. The water is of good quality except where the wells are located too near buildings.

Cisterns also are extensively used in all parts of the county, and in the western part they form the best sources of supply for domestic purposes, but many are in use in the eastern part, where good well water is available.

Springs are numerous throughout the county, but they vary greatly in size, being large in the eastern half of the county and small in the western half. As the spring water is usually hard, it is used but little for domestic purposes. A number of springs are, however, used for manufacturing, and a part of the supply for the village of Tyrone comes from a spring in the Kentucky gorge.

Most of the underground water used for manufacturing comes from the Winchester and Lexington limestones.

BOONE COUNTY.

SURFACE FEATURES.

Boone County, one of the most northerly counties of the Blue Grass region, is bordered on the north and west by Ohio River, whose channel here occupies a steep-sided gorge.

The surface of the county is a plateau, deeply trenched by narrow gorges near the river, but nearly level in the interstream areas, which

are occupied in large part by flat-topped divides. Altitudes within the county have an extreme range of over 500 feet—from about 420 feet above sea level along the Ohio to more than 940 feet on the highest parts of the upland. The descent from the level of the upland to the river is usually precipitous, and the small streams, which as a rule make the descent within a distance of 3 or 4 miles, have very steep gradients. The larger tributaries have cut deep channels for a distance of several miles back from the river.

The Ohio receives in this county water from many small tributaries and from three creeks of considerable size—Woolper, Gunpowder, and Big Mud Lick. These creeks not only drain the greater part of Boone County, but small areas outside of it. The drainage basin of Woolper Creek is largely north and west of Burlington; Gunpowder Creek receives the drainage of the south-central part of the county; and the southern end of the county drains into Big Mud Lick Creek, either directly or through Big Bone Creek.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

Above the rock in the southern part of the county is a deposit of residual clay, averaging 5 or 6 feet in thickness, which has been produced by the weathering limestones and shales of the Maysville. It varies in color from yellow to brownish red, and is usually dense where it was derived from the shales and more porous where the original rock was limestone. The porosity of these limestone soils seldom equals that of the loam derived from the Lexington limestone in Fayette County. The residual materials do not furnish water directly to wells and springs in this county, but they store the moisture and give it to the crevices and channels in the rock from which the wells and springs draw their supplies.

The northwestern part of the county is capped by a loesslike silt (see silt-loam soil, p. 33) to an average depth of 2 or 3 feet, with a maximum of about 6 feet. Beneath the silt is glacial drift, a few feet thick, composed largely of residual clay containing fragments of limestone and pebbles of chert, with occasional bowlders of granite. In the vicinity of Bullittsville and Hebron the glacial drift consists of water-deposited sand and gravel, but this phase is apparently restricted to the ancient channel of a small stream which existed before the deposition of the drift.

In the valley of Middle Creek there is a deposit of sand and gravel which locally exceeds 40 feet in thickness and which is not known to extend beyond the boundaries of the drainage basin. Above the gravel of this deposit, which has in some places been cemented into

a hard conglomerate, is a layer of sand several feet thick, capped by 5 or 6 feet of loesslike silt. The drift rests upon the original surface, which it has modified very little.

In the Ohio Valley near Bellevue the glacial drift forms well-defined knolls which rise to nearly 250 feet above the gravel terraces which border the river. In some places the residual soil has been very little disturbed. The drift has about the same color as the residual material from which it was largely derived.

The glacial deposits over most of the county serve the same purpose as the residual materials—that is, they store the water and supply it to openings in the rock below. The glacial materials are as a rule somewhat less porous than the residual, but they are much thicker and therefore hold a greater volume of water. Where the drift consists of sand and gravel it supplies water for both wells and springs. Rock springs, from the conglomerate in Middle Creek Valley, are very well known throughout the western part of the county. In the vicinity of Bullittsville and Hebron the glacial gravels supply remarkably pure soft water to half a dozen wells and a number of springs.

The hillside slopes underlain by Eden shale are usually covered by a mass of talus, composed of blocks of limestone with more or less silt or clay. The streams are constantly transporting this material toward the river, but the accumulation usually goes on more rapidly than the removal. The deposition of the material at the points where the tributary streams enter the main valley gives rise to alluvial fans. The talus deposits supply moderate quantities of water to springs and shallow wells.

The alluvium along the small streams is usually made up of coarse angular or subangular fragments mixed with silt or clay, the large fragments predominating to such an extent that the material is very porous. It contains large quantities of water in wet weather, but the supply is apt to be exhausted during periods of drought.

In the Ohio Valley the alluvial deposits are also very porous and they absorb a large amount of water, receiving not only that which falls directly upon the surface of the gravel but much drainage from the upland. These deposits furnish, at depths of 80 to 110 feet, an abundance of water which, although moderately hard, contains less inorganic matter than the water from the limestones.

CONSOLIDATED MATERIALS.

The surface rocks of Boone County include the Winchester limestone, which outcrops in the Ohio Valley and in the lower course of the tributaries of the Ohio; the Eden shale, which is exposed on the stream slopes for a distance of several miles back from the river but which does not reach the surface on the upland; and the Maysville

formation, which is at the surface over all the upland portion of the county. It is possible that the Lexington limestone forms a part of the channels of the streams near the southeast corner of the county, but important exposures of this rock are not found in the county.

The Winchester limestone in this region is from 40 to 50 feet thick and is exposed only in the lowest parts of the valleys. In some of the smaller stream valleys it may yield fresh water, but in most localities the water from this horizon is brackish and in many places it is sulphurous. Its quality would in general render it unfit for domestic or industrial uses.

The Eden shale, which overlies the Winchester limestone with a thickness of about 300 feet, furnishes practically no water for either springs or wells.

Overlying the Eden shale are the rocks of the Maysville formation, which comprise a series of interlaminated limestones and shales somewhat exceeding 200 feet in thickness. In the northern half of the county, especially in the vicinity of Burlington and Florence, the heavy bedded limestones of this series contain some caverns, not large enough to permit exploration, but indicated by numerous small sink holes. In this part of the county underground water conditions are greatly favored by the porosity and unusual thickness of the loose materials above the limestone. In the southern part of the county, where the shales of the formation are the predominant surface rock, the amount of underground water is smaller, although locally the occurrence of limestone beds furnishes more favorable conditions. The residual materials in this part of the county, being derived from argillaceous rocks, are rather heavy clays, and although they have great storage capacity they furnish only moderate quantities of water to the underlying rocks.

Wells in the limestone of the Maysville formation obtain water at depths ranging from 10 to 35 feet, but the amount of water varies greatly from time to time. The underground channels fill quickly after a rain, but the supply is soon lessened by dry weather, and during periods of drought the shallow wells and many of the springs may be dry. Where the upland borders the Ohio Valley numerous springs emerge from the contact of the limestone beds with the underlying shale layers. Many of these springs are situated 300 or 400 feet above the river; but there is, of course, no foundation in fact for the popular belief that they lie on the highest points of land, for the water comes from higher areas a short distance back from the river. The water found in the rocks of the Maysville formation contains considerable amounts of inorganic matter, but is not too hard for ordinary uses.

The Highbridge and Lexington limestones are under cover in this county, but where they were penetrated in drilling for oil near Big

Bone Springs some salt water and considerable gas were found. Here, as elsewhere in the Blue Grass region, the water in these formations occurs in channels which may or may not be encountered in drilling; but as neither formation supplies fresh water where it is buried beneath younger rocks, it is useless to drill into them for water for domestic or industrial purposes.

The St. Peter sandstone underlies Boone County at depths varying from less than 900 feet in the deeper valleys to 1,400 feet on the upland, but it has not been reached by any deep wells. It would furnish flowing wells in all the valleys which are cut below about 590 feet above sea level, including the Ohio Valley and the lower courses of its principal tributaries, but it is safe to say that the quality of the water would be the same as at Frankfort and Cincinnati, where the formation furnishes the strong salt-sulphur water commonly known as "blue lick" water.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

In the Ohio Valley wells penetrating the alluvium have been uniformly successful except at Taylorsport, where a fine sand was encountered which caused the abandonment of two wells. The Boone County distillery takes its entire water supply from the alluvium. On the upland, however, drilled wells have been unsuccessful, either failing to obtain any water or finding brines. A well drilled to a depth of 200 or 300 feet at Walton found no water, but encountered considerable gas. At Florence a drilled well between 150 and 200 feet deep obtained a small supply of water, said to be brackish, and attempts to increase the amount by exploding dynamite in the well were unsuccessful.

The following record of one of the three deep wells drilled for oil near Big Bone Springs was supplied by Mr. Geer, the driller:

Record of drilled well near Big Bone Springs.

	Feet.
Soapstone (very white) and limestone	0–100
Hard limestone; strong flow of salt water at 105 feet; small flow of gas at 160 feet	100–160
Limestone (light colored); strong flow of gas at 165 feet, and small flows of gas at 177 and 193 feet	160–500
A few feet of "slate," followed by limestone (alternating light and dark)	500–800

An incomplete set of samples from another well at the same locality was identified by E. O. Ulrich as follows:

	Feet.
Lower Lexington limestone (Hermitage and Logana)	150–240
Curdsville	240–288
Tyrone	288–330

A well drilled at one of the Big Bone Springs is reported to have obtained salt water at 150 and 500 feet. The flow was so strong that drilling was stopped. The water from the well has the same properties as that of the springs and is now being sold as Big Bone Spring water.

Shallow dug wells are numerous on the upland areas of Boone County and afford considerable water, though many of them fail in dry weather. Few wells have been dug in the last quarter of a century, and except in the northern part the old wells are gradually being abandoned in favor of cisterns, which provide most of the water for domestic use, some being in use even in the Ohio Valley where underground water is abundant.

BOURBON COUNTY.

SURFACE FEATURES.

Bourbon County is located in the east-central part of the Blue Grass region. Its surface is a gently rolling plateau, crossed by streams which flow in broad, shallow valleys. Through the central part of the county Stoner Creek, a tributary of Licking River, has cut a channel more than 200 feet deep, but over a large part of the area the relief does not exceed 100 feet. The long, narrow ridge which rises abruptly above the surrounding country in the southeastern part of the county received from the early settlers the name "Cane Ridge."

Stoner Creek receives the drainage from the entire county except small areas near the eastern and northern boundaries. The principal tributaries of this creek in Bourbon County are Strodes Creek, Coopers Run, Flat Run, and Townsend Creek. The northern and eastern parts of the county are drained by Hinkston Creek, which receives within the county several small tributaries, the largest being Boones Creek.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The large streams of Bourbon County are bordered by narrow strips of alluvium, composed of assorted sands and gravels, but the formation covers too small an area to be important as a water bearer.

The residual soils of the county consist of the porous loams and clays common to the Blue Grass region. They are usually about 3 feet thick, but in exceptional localities the thickness may be somewhat greater. These soils store moisture which is transmitted to the underlying rocks and assists in maintaining their water supply during dry weather.

CONSOLIDATED MATERIALS.

The rock formations of Bourbon County include the Lexington and Winchester limestones and the Eden shale.

The Lexington limestone forms the surface rock over a large part of the county west of the east side of Stoner Creek Valley and yields an abundance of hard water for springs and wells. Most of the wells obtain water at depths of 100 feet or less, but those which penetrate below the level of the surface streams or enter the Highbridge limestone may find salt-sulphur waters. Some of the springs in this county are exceptionally large and have fairly uniform flow.

The Winchester limestone is exposed in a narrow strip along the west and northwest boundaries of the county and covers a large area bordering the Lexington limestone in the eastern part of the county. Where this formation is at the surface it furnishes moderate quantities of hard water. It might also furnish water for deep wells, but such water would be too highly charged with salt and sulphur to be fit for ordinary uses.

The Eden shale covers the high ridges and hills in the southeastern part of the county and caps some of the hills in the northwestern part, and small exposures are also found in the northeastern part of the area. It furnishes little water except to springs and shallow wells.

The St. Peter sandstone, which underlies the county, would furnish an abundance of salt-sulphur water, but none of the wells would flow, and except in the bottoms of the valleys the water would probably not come within 200 feet of the surface.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

The water supply of Paris, the county seat, is taken from a stream near the city, and since the installation of a filter plant this supply ranks as one of the best in the Blue Grass region. In addition to the municipal supply, many cisterns and a few drilled wells are in use at Paris, and a large spring in the western part of the city supplies water for a number of families. Since the underground stream which supplies this spring passes under a thickly inhabited part of the city, the water can scarcely be regarded as safe, even though its use does not appear to be injurious.

Several hundred wells, ranging in depth from 30 to more than 100 feet, have been drilled in Bourbon County, and in most localities they have been very successful; but in a few places they have obtained no water, and some wells near Shawhan encountered strong brine which was unfit for use. Salt-sulphur waters are usually found at depths ranging from 30 feet in some of the valleys to 100 feet or more on the hills.

Dug wells are numerous throughout the county, but they are gradually being abandoned in favor of cisterns, from which the water for domestic use is commonly obtained. The average depth of the dug wells does not exceed 35 feet. Two deep wells in this county, one about 80 feet and the other 120 feet, were sunk by digging and blasting. As the residual clay is in few places more than 20 feet thick, the amount of rock which had to be removed must have made the sinking of these wells a difficult task.

The cisterns in general use are as a rule well constructed, and they receive such excellent care that they form very satisfactory sources of supply. The use of cisterns and a small hand engine for fire protection in the small towns of the county is strongly recommended.

Besides the spring at Paris, four other springs in the county supply large quantities of water, and springs of moderate size are found on nearly every farm. Several of the large plantations are supplied with water pumped from springs to reservoirs or standpipes and distributed to the buildings by gravity pressure.

BOYLE COUNTY.

SURFACE FEATURES.

The surface of Boyle County, on the southern border of the Blue Grass region, is greatly diversified. On the eastern boundary of the county is Dix River, flowing between nearly perpendicular walls of limestone in a gorge cut to a depth of more than 300 feet below the level of the gently rolling upland, which extends from the river westward to beyond Perryville and from the northern line of the county southward nearly to the line of the Louisville and Nashville Railroad. South of the Louisville and Nashville and west of the Cincinnati Southern Railroad is a deeply dissected area belonging to the mountainous province. The mountains here are somewhat lower than farther east in the Blue Grass region, and few of them rise more than 250 to 300 feet above the level of the upland. From the upland to the mountains the transition is usually abrupt, though the hills on the upland appear to be highest near the mountains.

Dix River receives the drainage of the eastern part of the county, its principal tributaries being Balls Branch, Wilson Run, and Harrod Branch. A small area in the southeastern part of the county is drained by the tributaries of the Hanging Fork, and the southwestern part drains to Salt River through North Rolling Fork and its tributaries. The northern half of the county, west of Atoka, is drained by Salt and Chaplin rivers, which head in the mountainous area of the county, and, after flowing northward for several miles, turn westward to the Ohio.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soils of Boyle County vary with the character of the underlying rock. On the shales of the Eden, Panola, and Ohio formations they consist of dense, heavy clays, at few places thicker than 2 or 3 feet; on the limestone formations they are usually much lighter and approach loam in texture; on the Waverly shale, which occupies only the mountain tops, they were derived from the sandstone layers, and consequently they have the texture of a sandy loam.

The unconsolidated materials in this county furnish directly little well or spring water; but here as elsewhere in the Blue Grass region the residual soils store considerable moisture and transmit it gradually to the crevices in the underlying rocks. The thin layers of gravelly alluvium found along some of the larger streams supply moderate quantities of water in the neighborhood of the streams.

CONSOLIDATED MATERIALS.

The rocks exposed at the surface in Boyle County include the Highbridge, Lexington, and Winchester limestones, the Eden shale, limestones and shales of the Maysville formation, the blue shales and limestones of the Panola formation, and the Ohio and Waverly shales, and the county is divisible into water provinces depending entirely on the character of the surface rocks.

The Highbridge limestone is exposed in the gorge of Dix River and in the lower parts of some of its tributaries and furnishes fresh water only along that stream.

The Lexington limestone forms the upper part of Dix River gorge, covers a large part of the upland between Dix and Salt rivers, and is also exposed along the headwaters of Chaplin River. The Winchester limestone forms a narrow band south of the Lexington limestone from Dix River to the Cincinnati Southern Railway, and west of this railroad it spreads over broad areas on the upland along the headwaters of Salt and Chaplin rivers and on the divides between these streams. West of Perryville the Winchester limestone reaches nearly to the Washington County line, and northwest of Danville it occupies some small areas near the Mercer County line. The areas underlain by both the Lexington and Winchester limestones present very favorable conditions for springs and wells, and drilled wells usually obtain an abundance of water at depths less than 100 feet. Water found in either formation, however, below the level of the surface streams is occasionally salt and is in many wells sulphurous, sulphur water having been found in some wells 50 feet deep.

Outside of the Winchester limestone is the Eden shale, with the Garrard sandstone member occupying the upper 100 feet. The

Eden shale forms a narrow band north of the mountains and covers considerable areas between the headwaters of Salt and Chaplin rivers and to the south and west of Perryville. The shale layers of the Eden furnish small quantities of water, and the sandstones, which are somewhat better water-bearers than the shales, furnish fair quantities of soft water for both springs and shallow wells. The Eden shale furnishes no water for deep wells.

The limestones and shales of the Maysville formation occupy a narrow strip, 1 to 2 miles wide, along the northern edge of the mountains and some narrow belts along the large streams in the southwestern part of the county. In most localities these rocks furnish enough water for domestic and farm use. They contain few large springs, but small ones are numerous and shallow wells are uniformly successful. They might also yield water for deep wells.

The Panola formation includes blue shales and limestones, which are overlain by the Ohio shale. The principal exposures of these formations in Boyle County lie along the northern side of the mountains and border the valleys of North Rolling Fork and Scrub Grass creeks. The formations are feebly developed, and few of the exposures exceed half a mile in width. At Johnson City, however, the black shale occupies a strip a little over a mile wide. In some parts of the county the Ohio shale is less than 40 feet thick. The water supplied by these formations is abundant, but is usually highly mineralized, alum, sulphur, iron, and magnesia being common constituents. In one locality salt water has been obtained from the Ohio shale.

The Waverly shale covers a large part of the area south of the Louisville and Nashville and west of the Cincinnati Southern railroads, its sandy beds forming the tops of the mountains. The thickness of the formation exceeds 300 feet in but few places in this county. The sandstone layers of the Waverly supply an abundance of soft water where they are exposed at the surface, and it is this formation that furnishes the numerous springs of so-called freestone water in the mountains. Few wells have been sunk in the Waverly, and deep wells in this formation would be unsuccessful.

The St. Peter sandstone underlies all of Boyle County and will probably yield flowing wells in some parts of Dix River gorge. The water from this formation is of the well-known "blue lick" type of the region.

DOMESTIC WATER SUPPLIES.

Springs, drilled or dug wells, and cisterns furnish the water for domestic supplies in this county. Underground water conditions are especially favorable in the valley of Salt River, where there are many drilled wells. In Perryville, for example, there are about 100

drilled wells, ranging in depth from less than 25 to more than 100 feet, with an average depth of less than 50 feet. These wells obtain water from the Winchester and Lexington limestones. At Mitchellsburg two drilled wells, about 100 feet deep, obtain water from the Panola formation, and springs and shallow wells in this formation will in most localities yield sufficient water for farm use. Several different kinds of mineral water are obtained from the Ohio shale at Junction City, Alum Springs, and Shelby City. At Mitchellsburg this shale supplies considerable white sulphur water, but the other types common to the formation have not been found at this place.

Dug wells are common throughout the county, but they are gradually being abandoned in favor of cisterns or drilled wells—a change which would appear to be most desirable, as the drilled wells and cisterns, when properly constructed and cared for, are much less likely to be contaminated by impure surface water than are the dug wells.

BRACKEN COUNTY.

SURFACE FEATURES.

Bracken County borders Ohio River in the southeastern part of the Blue Grass region. The altitude of Ohio River at the northwestern corner of the county is about 440 feet above sea level, and the higher parts of the county rise to a height of about 450 feet above the river. South of Brooksville there are some areas of level land, but elsewhere erosion has carved the surface into steep-walled valleys, separated by narrow divides.

The northern part of the county is drained by Locust Creek and other small tributaries of Ohio River. Licking River touches the southwest corner of the county, and the North Fork of the Licking forms the southern boundary and receives the drainage from nearly all of the southern half of the county. Its principal tributary within the county is Camp Creek. Kindale Creek, which heads near the southwest corner of Bracken County, crosses Harrison County and enters the Licking River north of Falmouth.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials of Bracken County consist of clays, yellow or reddish, and usually thin and stony on account of the great amount of erosion to which they have been subjected since the removal of the forests. In the northeastern part of the county, where the surface is nearly level, the residual clay is in places more than 3 feet thick. The glacial deposits of the county are restricted to the Ohio Valley, where they are represented by such materials as the conglomerate near Augusta. The terrace gravels rise to an altitude of 75 to 80 feet

above the river, and have the same general character here as in other counties of the Blue Grass region. Where they rest on dense rocks which are free from open crevices the residual materials yield a little water to springs and wells; elsewhere they supply water to the crevices in the underlying rock.

The alluvial deposits along the streams furnish an abundance of hard water, which is usually obtained by sinking drilled wells. Many springs issue from the alluvium along the banks of the Ohio, and wells procure large supplies at depths ranging from 80 to 110 feet.

CONSOLIDATED MATERIALS.

The surface rocks of Bracken County include the Lexington limestone, which is exposed in the stream beds and on the lower parts of the slopes, in most places less than 100 feet above the streams; the Winchester limestone, exposed along the main Licking River, North Fork, Ohio River, and along the lower courses of the tributaries which enter these streams; the Eden shale, which occupies the slopes of the valleys and covers a considerable area on the upland, the most extensive exposures being found near the southwestern corner of the county; and the Maysville formation, found capping the highest hills, covering considerable areas of the upland in the northeastern part of the county. The Maysville formation is represented in this county chiefly by the lower members, but some of the limestone beds which outcrop on the eastern edge of the county probably belong near the middle of the group.

The Lexington limestone will probably furnish no fresh water in Bracken County, but it may yield salt or salt-sulphur water.

Where the Winchester limestone is exposed in the valleys of the streams it furnishes moderate quantities of hard water. In most parts of the county, however, it will not yield fresh water, though deep wells may obtain from it salt-sulphur water.

In localities where it forms the surface rock the Eden shale yields moderate quantities of hard water to springs or shallow wells. Deep wells which penetrate this formation obtain either inadequate supplies or none at all.

The St. Peter sandstone underlies this county at depths ranging from less than 1,500 feet on the upland to about 1,000 feet in the Ohio Valley. This formation contains salt-sulphur water under sufficient head to give flowing wells in the valley of Ohio River and the lower parts of some of the large tributary streams. The Highbridge limestone, which rests on the St. Peter, will probably supply nothing but salt or salt-sulphur water in this part of the Blue Grass region.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Water for domestic purposes is obtained in this county from springs, dug, drilled, or bored wells, and from cisterns, the cisterns forming the most satisfactory source of supply.

A few very successful wells have been sunk in the alluvium of the Ohio Valley, the only failure resulting from locating the well too near the valley wall, where rock was encountered. A drilled well at Cummins Brothers' mill furnishes a large supply of water which is very satisfactory for use in the boiler of the mill. At Brooksville several unsuccessful wells have been sunk, and it does not appear probable that much fresh water can be obtained by drilling. An oil well sunk on the outskirts of the town encountered a small amount of hard water near the surface and strong salt-sulphur water at a greater depth.

Dug wells from 20 to 30 feet deep and springs of moderate size are common on the upland, and they furnish an abundance of water during a wet season, but both springs and wells are apt to fail in dry weather. Some of the springs in the valleys of the small streams yield brackish sulphur water. Along the banks of the Ohio springs are numerous when the stream is low, but they are usually submerged during high water.

CAMPBELL COUNTY.

SURFACE FEATURES.

Campbell County, lying between Licking and Ohio rivers, comprises the narrow belt of lowland along these streams and the upland area between them. The upland consists of a deeply dissected plateau with narrow interstream areas. Ohio River, where it borders the county, has an altitude of less than 540 feet above sea level, and the highest points on the upland are about 400 feet above the river. Licking River is somewhat higher than the Ohio, and the valleys of both streams have precipitous sides. Along the Licking, southwest of Alexandria, at a height of nearly 200 feet above the stream, is a rock terrace capped with a few feet of Tertiary sand containing pebbles of chert derived from the younger geologic formations to the south.

The principal streams of the county are Philips Creek, a tributary of Licking River, and Twelvemile Creek, a tributary of the Ohio. A number of smaller tributaries join each of the rivers. These tributary streams have very steep gradients, many of them descending 200 or 300 feet in a distance of 3 or 4 miles.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The rock formations of Campbell County underlie a thin mantle of unconsolidated, yellow or reddish-brown soil. In some places near the Ohio River this material contains fragments of rock and is probably of glacial origin, but over most of the county it has been weathered from the underlying rock. The residual soil is largely clay over the shale areas, but over the limestone areas it has the texture of loam.

These residual clays contain considerable water, but they yield very little directly to wells or springs. They serve, however, a valuable purpose in storing moisture and feeding it to the crevices in the underlying rocks.

Alluvial terraces of sand and gravel with a maximum thickness somewhat exceeding 110 feet, are found along Ohio River, where they reach an altitude of over 550 feet above tide. The alluvium in the Licking Valley also consists of sand and gravel, but the percentage of sand is greater than along the Ohio Valley and the deposit is not so thick. A thin deposit of coarse alluvium containing fragments of limestone with some clay, is usually found bordering the small streams. Along Licking River the rock terraces carry a deposit of porous sandy gravel, which was probably at one time nearly continuous, but much of which has been removed by erosion, so that it now appears only in small isolated patches.

The alluvium of the Ohio Valley is very porous and contains a large amount of water. A number of wells obtain water from these beds at depths of 80 to 110 feet, and the height of the water in the wells usually varies with the stage of the river. The rise and fall of the water is most marked in wells which penetrate coarse gravel near the bank of the stream, and the fluctuations usually lag behind the corresponding stages in the river. Many springs emerge from the alluvium just above the level of the river. The water from these gravels is moderately hard, but the degree of hardness varies considerably.

The alluvium along Licking River supplies water to springs along the river bank, and it would also furnish water to wells. The quality of the water is practically the same as that in the sand and gravel of Ohio River. The alluvium of the small streams furnishes some water in wet weather, but the supply is likely to fail in periods of drought.

CONSOLIDATED MATERIALS.

The Lexington and Winchester limestones are largely under cover in this county. Where exposed in the bottoms of the small valleys they supply moderate quantities of hard water, but where buried

under the younger formations they usually furnish only brackish water, which may contain considerable hydrogen sulphide.

The Winchester is overlain by from 250 to 300 feet of shales, with occasional beds of limestone, which represent the Eden shale. These rocks form the lower slopes of the stream valleys and rise to the upland near the borders of the county, and furnish small quantities of hard water to shallow wells and springs.

Above the Eden shale are the interbedded limestones and shales of the Maysville formation, which make the surface rocks over a narrow belt in the center of the upland portion of the county. Near the center of the county the limestone beds of the Maysville are the predominant surface rocks.

The rocks of the Maysville formation furnish the water supplies for shallow wells on the upland. Underground channels are numerous, and hence underground water conditions are good; but near the rivers, where the more shaly portions of the lower part of the Maysville are at the surface, the underground channels are smaller and the water conditions less favorable. In the central part of the county rocks of the Maysville yield water to many good springs and wells, but outside the central area the springs are smaller and the wells as a rule obtain small supplies. All the water from the Maysville formation is hard.

The Highbridge limestone is under cover in this county, but if penetrated by deep wells it would probably yield nothing but strongly mineralized water.

The St. Peter sandstone underlies Campbell County at depths of 900 to 1,000 feet in the Ohio Valley and 1,400 to 1,500 feet on the upland. It yields a strong salt-sulphur water, under head sufficient to give flowing wells in the valleys of Ohio and Licking rivers and in the lower parts of the valleys of the small streams which enter these rivers.

CARROLL COUNTY.

SURFACE FEATURES.

Carroll County is in the western part of the Blue Grass region, with the Ohio River forming its northern boundary. The upland surface of the county is a deeply eroded plateau with narrow divides and steep-sided valleys, the highest parts rising to an elevation of about 900 feet above tide or more than 450 feet above the Ohio. Along Eagle Creek, which forms the southeastern boundary of the county, is a well-developed rock terrace.

Kentucky and Little Kentucky rivers, which enter the Ohio in this county, have cut deep, narrow channels across it. The most important of the numerous smaller streams of the county are McCoots

Creek, a tributary of Ohio River, and Whites Run and Eagle Creek, tributary to the Kentucky.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

A large part of the upland is covered by a few feet of heavy clay derived from the decomposition of the underlying rock, which usually contains much shale. On the upland west of the divide which separates the tributaries of Ohio River from those of other streams, the surface is mantled by glacial deposits consisting of residual clay mixed with fragments of limestone with occasional pebbles and bowlders of other rocks. East of Carrollton, in a gap in the rock ridge which separates the valleys of Ohio and Kentucky rivers, the till forms a well-defined ridge less than one-half a mile wide [a] which appears to be a moraine. This moraine presents a nearly flat top, which is apparently due to a capping of loess like silt. The residual and glacial materials furnish very little water directly to wells, but they serve a valuable purpose in storing water and supplying it to the crevices in the underlying rock.

A heavy deposit of alluvium, consisting of sands and gravels which were deposited by waters from the melting of the Wisconsin ice sheet, is found in the Ohio Valley and fills the valley to a depth of slightly more than 100 feet, its surface forming terraces which rise to a height of nearly 100 feet above the stream. Wells 80 to 120 feet deep obtain an abundance of water in this deposit.

Along Eagle Creek and Kentucky River are thin deposits of alluvial sands and gravel which rise about 80 feet above the streams. The alluvium of Kentucky River furnishes a large quantity of water at depths of 100 feet or less, but that along Eagle Creek is in few places more than 30 feet thick and furnishes only moderate quantities of water. The thin deposits of coarse alluvium found along smaller streams is in most places but a few feet thick, and it yields water only during wet weather. The water obtained from all the alluvial deposits is moderately hard, but it is suitable for domestic use, and along Ohio and Kentucky rivers it is used for industrial purposes.

CONSOLIDATED MATERIALS.

The Winchester limestone is exposed in the valleys of all the principal streams in Carroll County, occupying the lower slopes, and above the Winchester, reaching to the lower parts of the upland, is the Eden shale. Resting on the Eden shale are the limestones and shales of the Maysville formation, which cover all the higher parts of the

[a] Leverett, Frank, Glacial formations of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902, p. 257.

upland. The Maysville and Richmond formations of this county contain a high percentage of shale, except in areas south of the Kentucky River, where the upper part of the Richmond consists of several feet of massive limestone.

The Winchester limestone furnishes some fresh water for shallow wells located in the valleys, but over the greater part of the county it will furnish nothing but salt-sulphur water. The water of the salt-sulphur spring at Sanders, which comes from this formation, closely resembles the famous "Blue Lick" water but contains less mineral matter. This may be due to the entrance of surface water.

The Eden shale furnishes little water except near the surface, and wells and springs in this formation are apt to fail in dry weather.

The limestone layers of the Maysville and Richmond formations furnish water for the shallow wells and springs on the upland, the supply usually being ample for a farm, except in very dry weather. Most of the wells obtain water at depths less than 35 feet, and it is practically useless to sink wells deeper than 50 feet in the areas covered by these rocks. The water from the limestones of the Maysville and Richmond formations is hard, but is satisfactory for domestic use. The massive limestone of the Richmond formation supplies considerable water in many places.

Experience has shown that the Lexington and Highbridge limestones, when buried beneath the younger formations, as they are in Carroll County, furnish salt or salt-sulphur water, and it is useless to attempt to obtain fresh water from them.

The St. Peter sandstone, which should be reached at depths of 900 to 1,000 feet in valleys of the streams bordering this county, will furnish flowing wells of salt-sulphur water in the valleys of Eagle Creek and Ohio and Kentucky rivers. On the upland the St. Peter lies deeper, and the water does not have sufficient head to force it to the surface.

CLARK COUNTY.

SURFACE FEATURES.

Clark County is situated on the southern edge of the Blue Grass region. The surface is greatly diversified, varying from the gently rolling, nearly level, areas in the western and northern parts, with the streams flowing in broad shallow valleys and the divides flat topped or slightly rounded, to the rugged area in the southeast corner of the county, where the mountains rise 300 to 400 feet above the level of the upland. Along the southern boundary of the county the surface is cut by the deep narrow gorges of the tributaries of Kentucky River, and local variations in relief are found as that river passes from areas of easily eroded rocks where the slopes are gentle to areas in which the rocks are more resistant and form vertical cliffs.

The drainage of Clark County is divided almost equally between Licking and Kentucky rivers, the watershed which separates the two systems passing nearly east and west through Winchester. From the district north of this line the drainage is carried to Licking River through Stoner Creek, which heads a few miles east of Winchester. The principal tributaries of Stoner Creek in Clark County are Donelson Creek, Pretty Run, and Strodes Creek. The principal tributaries of Kentucky River within the county are Howards Creek, Twomile Creek, Fourmile Creek, and Upper Howards Creek. Boones Creek, on the western boundary of the county, and Lulbegrund Creek, on the eastern boundary, are important tributaries of Kentucky River which drain small areas of Clark County.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The unconsolidated materials consist of residual clays and loams on the shale and limestone areas of the upland and of alluvial sands and gravels in the gorge of Kentucky River. As in other counties of the region, the residual soils yield no water directly to wells, but they furnish considerable moisture to crevices in the underlying limestone. The alluvial sands and gravels in the gorge of Kentucky River would probably provide excellent supplies for shallow wells.

CONSOLIDATED MATERIALS.

The Highbridge limestone is exposed in the walls of the gorge of Kentucky River and in the lower parts of the tributary streams in the southwestern part of the county. Where it appears at the surface in the southern part of the county it will supply moderate quantities of hard water for springs and wells, but elsewhere in the county it will yield only salt or salt-sulphur waters.

The Lexington limestone is exposed over large areas along Strodes and Stoner creeks and on the upland in the southwestern part of the county, and some small exposures are also found in the stream valleys south of Winchester. Where this limestone is at the surface it furnishes an abundance of hard water for springs and wells, but at depths of about 50 feet in the valleys and 100 feet on the uplands it furnishes salt or salt-sulphur water. In the northeastern part of the county the salt-sulphur water is encountered in some wells at a depth of less than 50 feet. Some of the springs in this formation in the northwestern part of the county are exceptionally strong, and most of the drilled wells have been successful.

The Winchester limestone occupies a narrow strip along the boundary of the Lexington exposures and covers a large area in the northwestern part of the county, and furnishes moderate quantities of hard

water for springs and shallow wells. In wells exceeding 50 feet in depth the water is usually strongly saline, and in some of them it is sulphurous.

The Eden shale occupies a large area in the central and eastern parts of this county, the Garrard sandstone member reaching a thickness of more than 100 feet. The formation furnishes small quantities of hard water to shallow wells, but drilled wells obtain no water from it below a depth of 25 to 30 feet. Most of the springs in the Eden shale are weak, and many of them fail during dry weather.

Rocks of the Maysville formation cover a large part of the southeastern and eastern parts of the county, and the higher hills in the southeastern part of the county are capped by a deposit of sandy shales containing some beds of earthy limestone which may represent the Richmond formation. The Maysville and Richmond rocks furnish considerable water for springs and shallow wells, but few deep wells obtain any large supplies of water from them.

The Panola formation, which outcrops over a large area in the southeastern part of the county, consists of about 50 feet of limestone containing interbedded shale, in many places sandy, overlain by about 5 feet of yellow magnesian limestone. The limestone layers of the Panola yield in some localities considerable water for springs and shallow wells, but the water is usually strongly charged with magnesia.

The Ohio shale occurs in the same localities as the Panola formation, but the areas are somewhat more restricted. The Waverly shale is exposed in the southeastern part of the county, but its areal extent is small. The Ohio shale and the shales of the Panola formation furnish a large variety of mineral waters, the most common types being alum, chalybeate, and sulphur. In the eastern part of the county some of the springs from these shales supply medicinal waters for a health resort.

The St. Peter sandstone underlies Clark County and will probably yield flowing wells in Kentucky River gorge north of the large fault, and possibly in the region south of the fault. On the upland the water would come within 300 or 400 feet of the surface in but few localities. In this county, as elsewhere in the Blue Grass region, the water would be highly saline, and consequently unfit for domestic or industrial uses.

STRUCTURAL FEATURES.

The rocks of Clark County dip gently toward the southeast, the only important structural feature being the large faults in the southern part of the county. One of these extends from about a mile north of Ruckerville in a direction slightly south of west to a point about a mile north of Valley View. Kentucky River crosses this fault

six times on the southern line of the county, and thus the fault plane is alternately in Clark and Madison counties. Near Ruckerville this fault is represented by a small fold that gives place to a fault with a gradually increasing displacement toward the west, until it reaches a maximum of nearly 400 feet near Cleveland.

Another fault begins at Kentucky River below Jacksons Ferry and extends northeastward into Montgomery County near Kiddville. The maximum displacement along this fault is less than that of other faults, but it amounts to nearly 300 feet. In both of these faults the rocks on the northern side of the fault plane have been lifted with relation to those on the south. In the fault first mentioned the Highbridge limestone on the north side of the fault has been brought to the level of the Garrard sandstone member of the Eden shale on the south, and in the other fault the upper part of the Lexington limestone on the north side reaches the level of the Garrard sandstone member on the south.

WATER FOR DOMESTIC AND INDUSTRIAL SUPPLIES.

The water for Winchester, the only large city in Clark County, is taken from reservoirs on a small stream a few miles from the city, and the supply is ample for all the prospective needs of the community.

Many good springs are found in all parts of the county, the largest being in the northern half, but few of them supply more water than is needed for a single farm.

Drilled wells, ranging in depth from less than 50 to more than 125 feet, are numerous in the vicinity of the Lexington and Eastern Railroad junction and to the north and west of Winchester. At Winchester and eastward along the Lexington and Eastern Railroad salt and salt-sulphur waters predominate, while to the north and west of Winchester ordinary hard water is usually obtained. In the southern part of the county there are few drilled wells, though some were reported at Kiddville, where they obtain mineral water. The many dug wells in the county are not much used, except when other sources of supply fail.

FAYETTE COUNTY.

SURFACE FEATURES.

Fayette County lies in the very heart of the Blue Grass region. On its southern boundary is the gorge of the Kentucky, and except near this river, where many of the streams have cut narrow channels 200 or 300 feet deep, the country is essentially a plateau with a gently rolling surface, presenting, however, considerable diversity. Variations in altitude of 50 to 100 feet within short distances are many,

and the extreme range within the county is more than 500 feet, for there is fully that difference between the surface of the Kentucky and that of the highest parts of the upland.

The drainage of the entire county is into Kentucky River. That of the southeastern corner reaches the river through Boone Creek; that of the south-central part through East Hickman and Little Hickman creeks; and that of the north-central and northern parts through Elkhorn Creek, which is formed by the union of three branches—North Elkhorn, South Elkhorn, and the town branch—and which joins the Kentucky in the northern part of Franklin County. From the source of North Elkhorn Creek to the point where the water enters Kentucky River the distance is nearly twice as great as is the distance from the source of the same stream to Kentucky River on the south. The direction of the streams seems to have been established by the original slope of the surface of the Lexington peneplain and by the course of the underground drainage, which developed before the peneplain was uplifted. The divide between the northward and southward flowing streams extends from Brannon northeastward to Lexington, and thence southeastward past Chilesburg. The flat areas along this divide and along the divides between the other stream valleys form the catchment areas for underground streams. The best defined of these streams flows through Russell Cave, but there are many smaller ones. The presence of the underground channels is indicated by numerous sinks and springs.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The rocks nearest the surface in Fayette County are overlain by residual material, usually red or yellow, varying in thickness from a few inches to more than 25 feet, the average being probably 5 or 6 feet. On the Lexington and Highbridge limestones the soil is made up of the comparatively insoluble constituents of these rocks; on the Eden and Winchester formations it is made up in part of the insoluble constituents of the limestone layers and in part of the fragments into which the many shale layers of these formations break up on being exposed to weathering. The soils on the Lexington and Highbridge limestones are for the most part loamy, but those on the Winchester limestones and Eden shales usually contain a large amount of clay. In the residual clay on the Lexington limestone there are many nodules of chert arranged in bands, much as they were in the original rock. As the underlying limestone has been removed by solution the soil has settled, the most marked settlings taking place along the joints where the water circulated freely and the limestone was dissolved rapidly. This unequal sinking has caused the chert beds

to bend down at the joints, leaving a series of arches over the heavy blocks of limestone. Because the solution along the joints was unequal the amount of downward curvature varies, and in some places, where the roof of a cavern has fallen, the chert is entirely gone.

Except in the city of Lexington, few wells obtain water from the residual material, but the material serves a valuable purpose in storing water and feeding it gradually to the underground streams in the limestone.

CONSOLIDATED MATERIALS.

The rocks of Fayette County are all of Ordovician age, the formations ranging from the Eden shale down to and including part of the Highbridge limestone. The greater part of the surface is made up of the Lexington limestone, but the Winchester limestone lies at the surface over considerable areas in the northwestern and southeastern parts of the county. In the extreme southeastern corner the Highbridge limestone is exposed in an area a few square miles in extent. A strip of Eden shale several miles long and less than half a mile wide extends in a northeast-southwest direction through the center of the county. These rocks lie in an almost horizontal position, and except for the faults that have brought the Eden shale into contact with the Lexington limestone they have been subjected to very little disturbance.

The principal water-bearing formation in the county is the Lexington limestone, which supplies many springs, some of them of large size, and most of the drilled and dug wells. The waters of this limestone are of two kinds—hard waters, with short underground courses, yielded by the shallow wells and by practically all of the springs; and mineral waters, usually alkaline, many of them containing salt, sulphur, and other mineral matter in noticeable quantities, supplied by many of the drilled wells in different parts of the county. Of these the flowing well on the Hisle farm is a noteworthy example. Underground drainage is favored by the topography of the area near Lexington and in the north half of the county, and in these areas water is abundant; elsewhere it is found in smaller quantities, but there are few farms on the Lexington limestone area without at least one good spring, and some of the farms have a large number of springs.

The Highbridge limestone furnishes considerable quantities of water for dug and drilled wells and a few springs of moderate size, but its surface is too deeply dissected to allow the formation of large underground streams. In quality the water is practically the same as that in the Lexington limestone, and ordinary hard waters and mineral waters are most important.

The Winchester limestone is of slight importance as a water bearer except in the southeastern part of the county, for the layers of shale separating the limestone beds prevent the formation of extensive underground channels. Shallow wells in this formation yield hard water, but some of the deeper wells penetrating it obtain salt-sulphur water.

The Eden shale is so dense as to be almost impervious, and the water supplied by it is always meager in quantity and often poor in quality.

The St. Peter sandstone underlies Fayette County, but the depth at which it would be reached is not certainly known. The horizon that supplies the flowing well at Frankfort was reached at a depth of 900 feet. In the Kentucky gorge, on the southern boundary of the county, the depth to this horizon would probably be less than 900 feet. It is doubtful if the St. Peter sandstone would furnish a flowing well in the Kentucky River gorge, and as the head of the water from the St. Peter is only about 580 feet above sea level, no wells drilled on the upland to this formation would flow. The water from the St. Peter is too highly mineralized for domestic or industrial uses, but it is considered valuable for medicinal purposes. Its composition is shown by the analysis of the water from the Old 76 distillery. (See p. 212.)

WATER FOR DOMESTIC AND INDUSTRIAL SUPPLIES.

The only public supply in the county is in the city of Lexington (see list on p. 85), but the private supplies of the stock farms rival the best city supplies in efficiency and in detail of construction. Many of the smaller farms provide water for stock by means of ponds constructed to retain surface water, but most of the large farms use underground water, either from springs or wells. In some places the spring water is merely impounded, but in others it is pumped to a tank from which it is distributed to the different parts of the farm. The wells in most common use are of the drilled type and range in depth from 30 to nearly 300 feet. The height to which the water rises varies greatly in different wells, and wide variations in the quantity and quality of the supply are also shown. The only flowing well noted in the county is on the Hisle farm.

The uncertainty of wind power has led to the adoption of the gasoline engine for pumping water on most of the large stock farms.

The water of the shallower drilled wells is apt to be hard, with much lime and magnesia and smaller quantities of other mineral compounds, while that of many of the deeper wells is alkaline, containing more or less salt and sulphur and other less noticeable ingredients. Although these general qualities are ascribed to the shallow and deep wells, respectively, it does not follow that all deep wells

contain highly mineralized waters or that shallow wells never supply them. The difference appears to be based on the relation of the underground stream to the surface drainage. Attention is called to the chemical analyses (Nos. 24 and 25, p. 212) of the remarkable alkaline water of the well at the depot of the Cincinnati Southern Railway in Lexington.

A few wells, ranging in depth from 15 to 30 feet, dug and blasted into the rock, are still used in this county to supply water for stock and domestic purposes. The water from these wells is always hard, the supply is apt to fail during periods of drought, and they are subject to pollution by surface water. They can not therefore be regarded as forming an entirely satisfactory source of supply. Most of the rock wells extend down to the solid limestone, and as a rule the water seeps in from the earth or cracks in the rock, although in some wells a definite underground stream is encountered. A good example of this is furnished by a 15-foot well at Athens, in which the water rises nearly to the top within a few hours after each rain and then gradually falls until it reaches its normal level with a depth of 3 feet.

On most farms the water for drinking is obtained from cisterns, and on some of them the entire domestic supply is drawn from this source. The cisterns are as a rule well cemented and many of them are provided with filtering devices. Chain pumps are in high favor because of the aeration resulting from the falling back into the well of much of the water raised. Such aeration is, however, of doubtful value, and the use of chain pumps allows dust and insects to get into the water and increases the possibility of contamination. More effective filtration and the adoption of pumps that will exclude foreign matter are greatly to be desired.

Cisterns also form the chief source of supply for most of the small towns in various parts of the county. In some settlements of more than a hundred people only one or two wells may be in use.

In the city of Lexington, in addition to the public supply, many cisterns and a few wells furnish water for domestic purposes. The danger of pollution of underground waters in a city like Lexington is great, and the use of such waters for domestic supplies can not be too strongly condemned. The underground drainage appears to converge toward the town branch of Elkhorn Creek, and the wells outside the city should be comparatively free from contamination by city sewage. If the custom of allowing city sewage to enter the underground channels were entirely discontinued, the quality of the underground waters would undoubtedly be improved; but the danger of pollution by surface drainage would still remain and the waters would probably never be entirely safe for domestic use.

FLEMING COUNTY.

SURFACE FEATURES.

Fleming County, located on the eastern edge of the Blue Grass region, includes on its eastern border a strip 6 or 8 miles wide belonging to the mountainous part of the State. The topography of this strip is rugged, the flat-topped mountains rising abruptly 400 to 500 feet above the valleys, which are from 1 to 2 miles wide. West of the mountains is a belt of country 10 to 15 miles wide whose gently rolling surface presents broad interstream areas separated by shallow valleys.

The southern and a large part of the western boundary of the county is formed by Licking River, which receives the drainage of the southern part of the county through Fox and Locust creeks and many smaller streams, and of the central part through Fleming Creek, which enters the river just west of the Robertson County line. These streams flow in valleys cut from 100 to 300 feet below the surface of the upland and separated by divides in many places only a few rods wide. The drainage of the northwestern part of the county reaches the Licking through Johnson, Elk, and Buchanan creeks, and that of the northern and northeastern parts enters the North Fork of the Licking through a number of small streams.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials of Fleming County vary with the geologic formations from which they were derived. On the Eden shale the soil is a thin, stony, yellow or reddish clay; on the rocks of the Maysville and Richmond formations brownish or reddish clays are found, which are usually thicker and more porous than the clays derived from the shale formations; on the Silurian and Devonian shales the deposits are dense, light-colored clays. The Silurian limestones decompose to a rather porous red clay. The Waverly shale occurs only on the slopes of the mountains and is covered with coarse débris which has fallen or been washed down the hillsides; the sandstone of the Waverly disintegrates to a light sandy loam, which is in most places very porous.

The residual materials furnish no water to wells or springs except where they rest on dense rocks like the Eden or Siluro-Devonian shales, but where underlain by limestone formations they may store considerable water, which is, in part, supplied to the crevices in the rock.

CONSOLIDATED MATERIALS.

Along the western edge of the county the Winchester limestone is exposed in the valleys of Licking River and its principal tributaries, but not far from Sherburne its eastward dip carries it below the

drainage levels. In the valleys of the streams where it forms the surface rock this formation yields some hard water for wells, but in other parts of the county water obtained from it will contain salt and salt-sulphur compounds.

Along the streams and on the upland in the western part of the county the Eden shale forms the surface rock, but few of its exposures are more than 3 or 4 miles wide. This shale furnishes some water for springs and shallow wells, which are, however, apt to fail in dry weather. At depths of 30 feet or more below the surface it yields no water.

East of the exposures of Eden shale is a belt of limestone of the Maysville formation, which passes beneath the Richmond formation along a line extending from a point south of Tilton northeastward to about a mile east of Flemingsburg, and thence northward to the north line of the county. The eastern boundary of the Richmond formation follows Licking River from the east line of the county to a point near Wyoming, Bath County, and thence passes northward in a sinuous line west of Grange City, Millsboro, and Poplar Plains and east of Flemingsburg and Mount Gilead. The Richmond extends much farther east in the valleys than on the uplands, and some narrow bands or isolated exposures of it are found east of the line just mentioned. The limestones of the Maysville formation provide exceptionally good conditions for underground water and in most places furnish an abundance of hard water for springs and shallow wells. Drilled wells may encounter gas or water containing petroleum or hydrogen sulphide gas at depths of 60 to 150 feet. The rocks belonging to the Richmond formation as a rule present less favorable conditions for underground water than those of the Maysville, because of the high percentage of shale they contain; but most of the springs in this formation yield moderate amounts of hard water, and most of the shallow wells obtain good supplies.

Above the rocks of the Richmond formation and covering all the rest of the county except the mountainous areas are the shales and limestones of the Silurian and Devonian periods, consisting, in ascending order, of about 25 feet of yellow magnesian limestones containing beds of shale in the lower and upper parts, nearly 100 feet of blue shale, and 150 feet of black carbonaceous shale. In some localities a thin deposit of concretionary iron ore is found at the top of the lower shale bed, and at one locality about 5 feet of yellow magnesian limestone was observed at the base of the black shale, but neither of these deposits appears to be widely distributed in the county. Linney correlated the lower shales and limestones to within a few feet of the black shale with the Silurian; the black shale with the beds of limestone at the base he considered Devonian.[a] The blue shale of this

[a] Linney, W. M., Geology of Bath and Fleming counties: Geol. Survey Kentucky, 1886, pp. 67–77.

series presents unfavorable conditions for underground water, though some wells derive a little water from the unconsolidated materials above it. The limestones usually furnish shallow wells with an abundance of hard water, commonly containing considerable magnesia. The black (Ohio) shale supplies many springs of highly mineralized water, usually containing either alum or sulphur.

Above the Ohio shale is a greenish, even-bedded sandstone, about 180 feet thick, with many interbedded shale layers. This sandstone caps the mountains, and being more resistant than the shale below, it prevents rounding of the slopes. The sandstone, with its interbedded shale, was called sub-Carboniferous sandstone by Linney[a] and Waverly shale by Campbell.[b] The Waverly shale yields an abundance of soft water, supplying the well-known "freestone" springs so numerous along the mountain sides. It is probable, also, that the spring water of the Ohio shale was originally absorbed by the Waverly shale and became mineralized after emerging from that formation during its passage through the joints in the shale.

The Lexington and Highbridge limestones and the St. Peter sandstone are deeply buried in Fleming County, but would yield salt and salt-sulphur waters to deep wells. The water from the St. Peter would probably rise nearly to the surface in the valley of Licking River at the western boundary of the county, but it is doubtful if surface flows could be obtained except near the northwest corner of the county, where a small area is less than 590 feet above sea level.

FRANKLIN COUNTY.

SURFACE FEATURES.

Franklin County, which lies in the southern part of the Blue Grass region, includes two distinct topographic provinces which coincide closely with the exposures of different geologic formations. That part of the county lying east of Kentucky River and south of a line drawn from Switzer to the Kentucky just north of the mouth of Elkhorn Creek is an upland province, with a gently rolling surface of low relief; the rest of the county, west of the river, is deeply dissected by innumerable valleys separated by narrow ridges. In general, the transition from one of these provinces to the other is gradual. Altitudes within the county have a range exceeding 400 feet.

Kentucky River crosses this area from north to south, receiving the drainage of the county through Elkhorn and Benson creeks and numerous smaller streams. From the south line of the county to the mouth of Elkhorn Creek the walls of the Kentucky gorge are precipitous; from this point to the northern end of the county a well-

[a] Linney, W. M., Geology of Bath and Fleming counties: Geol. Survey Kentucky, 1886, pp. 78, 79.
[b] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

defined rock terrace, from 80 rods to 1 mile wide, rises to an altitude of about 500 feet above sea level. Above this terrace the valley walls rise abruptly to the level of the upland. This broad terrace is well developed along Elkhorn Creek, where it reaches an altitude of over 600 feet above tide. Along the Kentucky south of the mouth of Elkhorn Creek, where the terrace may be observed at several points, it is as a rule less than one-half mile wide. In some places this terrace surrounds hills that have been separated from the upland by the erosion of the streams. Such isolated remnants of the upland may be seen at Bethel Church on Elkhorn Creek and at Gratz and Frankfort on Kentucky River. The separation of these hills from the upland appears to have taken place in part since the formation of the rock terrace, for the channels surrounding them have been excavated below the level of the terrace.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials on the limestone areas of the county comprise brownish or reddish loams derived from the decomposition of the underlying rocks; on areas underlain by shale they consist of stiff yellow or red clays. These materials furnish little water for wells or springs except where they are underlain by relatively impervious rock, and even in such places the supply is small and is apt to fail in dry weather.

Along Kentucky River and on the limestone terraces that border the principal streams are considerable areas of sandy alluvium which yield large quantities of water to springs. Few wells have been sunk in the alluvium in Franklin County, but those drilled obtained an abundance of moderately hard water at depths ranging from 50 to 80 feet. This deposit will furnish large quantities of water only in places where it extends below the level of the river; where it rests upon the limestone terraces the water escapes through channels in the rock.

CONSOLIDATED MATERIALS.

The Highbridge limestone is exposed along Kentucky River from the southern line of the county to a point about 9 miles beyond Frankfort, where its dip carries it below water level. In localities where it forms the surface rock it furnishes hard water for shallow wells; but where it is covered by other formations it yields brines which are as a rule charged with sulphur.

The Lexington limestone forms most of the surface rock from the southern line of the county to Switzer and on the terraces along the principal streams, and is also exposed along Benson Creek from Kentucky River to the west line of the county. In most places it

contains many water-bearing channels which supply an abundance of water for both springs and wells, and nearly all the large springs of the county get their water from this formation. Many of the wells sunk below the level of the surface streams, however, obtain salt or salt-sulphur water, and water of this character may be expected in the Lexington limestone where it is covered by younger formations.

A narrow strip bordering the exposures of Lexington shows the Winchester limestone, and the formation is also exposed in a large area east of Kentucky River in the southern part of the county. In most localities where it forms the surface rock the Winchester furnishes moderate quantities of hard water to springs and shallow wells; but wells which penetrate the limestone to depths below the level of the surface drainage obtain salt or salt-sulphur.

The Eden shale is exposed over a large part of the county west of Kentucky River and north of Elkhorn Creek on the east side of the river, and furnishes small quantities of water for springs and shallow wells. Farther below the surface, however, this rock is too dense to yield water.

The limestone of the Maysville formation may occur on some of the high hills near the Shelby County line, but it is not extensively developed in Franklin County.

The St. Peter sandstone lies at a depth of 790 feet in Kentucky River gorge near the southern line of the county and 900 feet at Frankfort. On the upland the maximum depth to this formation would probably be less than 1,500 feet. Flowing wells of salt-sulphur water can be obtained from the St. Peter wherever the altitude of the surface is less than 580 feet above sea level.

STRUCTURAL FEATURES.

The rocks of Franklin County dip slightly toward the southwest and present no interesting structural features except the faults in the northern and eastern areas. In the eastern part of the county are two faults which extend from south of Stamping Ground northwest into Franklin County. The area between these faults has been dropped so that the Eden shale is brought into contact with the Lexington limestone. Prof. Arthur M. Miller has informed the writer that there is another small fault west of Kentucky River in the northern part of Franklin County.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Dug or drilled wells, springs, and cisterns supply the greater part of the water used in Franklin County. The water supply of Frankfort is taken from Kentucky River, and as no cities are located on the river above that city the supply should be satisfactory. A large amount of sediment in the water renders it somewhat objectionable

for some purposes, but this sediment might be removed at comparatively small expense by the use of a mechanical filter.

The alluvium of the Kentucky gorge formerly supplied water for a number of wells at Frankfort, 80 to 110 feet deep, but these wells have nearly all been closed in accordance with the advice of the health officers.

Drilled wells from 50 to 150 feet deep are numerous, and most of them yield excellent supplies, though the water of some of the deeper wells is sulphurous. In the vicinity of Jett there are nearly a score of drilled wells. At Frankfort drilled wells have been less successful, and some absolute failures are reported. The Murray well at Frankfort is 1,250 feet deep and encountered a strong flow of salt-sulphur water in the St. Peter sandstone at a depth of 900 feet. The water from this well was formerly sold for medicinal purposes, but the sales gradually diminished until the enterprise was abandoned. As the water undoubtedly has considerable value in the treatment of certain diseases of the organs of digestion and excretion it should find a ready market.

Many cisterns are used in the areas of the county underlain by the Eden shale, for the water furnished by this formation is in some places poor in quality, is meager in quantity, and the supply is apt to fail entirely in very dry weather.

GALLATIN COUNTY.

SURFACE FEATURES.

Gallatin County occupies a narrow area between Ohio River and Eagle Creek in the northwestern part of the Blue Grass region. Except along the streams, where level strips of alluvium are found, the surface of the county is a deeply dissected plateau, with altitudes ranging from 445 feet above sea level at the Ohio River level to more than 900 feet on the upland. A rock terrace along the valley of Eagle Creek has an altitude of about 530 feet above sea level. Leverett[a] mentions an abandoned valley nearly 650 feet above sea level, which passes from Eagle Creek, 2 miles north of Glencoe, to Ohio River just north of Warsaw, and is closely connected with a similar valley which extends northward to the South Fork of Big Bone Creek.

A narrow belt on the east side of the county drains into Eagle Creek, but the principal drainage is into Ohio River through Stephens Creek, Craigs Creek, the South Fork of Big Bone Creek, and numerous smaller streams. All of these streams descend from the level of the upland to the Ohio within a very few miles, and most of the valleys have precipitous slopes.

[a] Leverett, Frank, Glacial formations of the Erie and Ohio basins: Mon. U. S. Geol. Survey, vol. 41, 1902, pp. 114–115.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The glacial deposits in Gallatin County consist of patches of clay containing some pebbles, and are practically restricted to the area draining to Ohio River.

The residual materials that cover so large a part of the county are made up of yellow to reddish clays which have been derived from rocks containing a large percentage of shale, and hence they are usually heavy. Where the residual materials rest on the Eden shale they supply a little water to wells. They also feed water to underlying rocks from whose crevices the wells and springs of the upland draw most of their supplies.

The usual deposit of alluvium, which is here arranged in three terraces lying at altitudes of 450, 470, and 495 feet above tide, is found in the Ohio Valley. An alluvial deposit consisting of sand with a few pebbles occurs in the valley of Eagle Creek, and thin patches of alluvium were observed on the terrace bordering Eagle Creek and in the abandoned channels which extend from this creek to Ohio River and Big Bone Creek. The alluvium of the Ohio Valley supplies large quantities of moderately hard water at depths ranging from 60 to 110 feet, and a number of springs emerge from it along the banks of the river. The alluvium along Eagle Creek furnishes some water for springs and shallow wells, but the supplies from these sources are very little utilized.

CONSOLIDATED MATERIALS.

The Lexington and Highbridge limestones are deeply covered by younger formations over the greater part of Gallatin County, though the Lexington is exposed along Ohio River in the vicinity of Warsaw. At such depths these formations furnish only salt or salt-sulphur water, unfit for any ordinary purposes.

The Winchester limestone occupies the lower slopes of the Ohio Valley and is also exposed along Eagle Creek on the east side of the county and in the valley of Big Bone Creek on the northern boundary. In the valleys of the streams where it is at the surface this limestone yields to shallow wells a supply of ordinary hard water, such as is commonly found in limestones; in localities where it is deeply covered, as over a large part of the county, its water is salt and as a rule contains sulphur.

The Eden shale occurs in the valleys of all the large streams and reaches well up toward the upland over a large part of the county. This formation yields practically no water to deep wells, and the moderate supply for shallow wells enters as a rule at or near the base of the unconsolidated materials.

The lower members of the Maysville formation cover the higher parts of the upland in Gallatin County. These rocks contain much shale and the underground channels are small. Except in very dry weather, however, they supply sufficient water for farm use, most of the wells being less than 35 feet deep. Springs are numerous in this formation, and some of them flow during the driest seasons.

The St. Peter sandstone probably lies 700 to 900 feet deep in the valleys of the principal streams and would undoubtedly yield salt-sulphur water, such as it supplies elsewhere in the region, under sufficient head to flow in the valleys of Ohio River and Eagle Creek where they border Gallatin County.

GARRARD COUNTY.

SURFACE FEATURES.

Garrard County is on the southern edge of the Blue Grass region, its northern boundary being formed by Kentucky River and a part of its western boundary by Dix River. The surface of the northwestern and central parts of the county is gently rolling, except near the boundaries, where the streams have cut deep, narrow gorges from 100 to 400 feet below the level of the upland; that of the northeastern part is deeply dissected by numerous streams, whose deep valleys are separated by narrow divides; and that of the southern end is diversified by mountains which rise abruptly to a height of nearly 500 feet above the level of the broad intervening valleys. Some of the finest blue grass land of the region is found in the northern end of this county.

The drainage of the eastern part of the county passes into Kentucky River through Paint Lick Creek; that of the central part reaches the Kentucky through Sugar, Davis, and Cane creeks and several smaller streams. The drainage of the western and northern parts of the county is to Dix River, chiefly through Boones, Drakes, and Coopers creeks.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials in Garrard County exhibit wide variation in texture, and consequently they differ greatly in water capacity in different parts of the county. On the Lexington and Winchester limestones and the limestones of the Richmond formation they are, as a rule, rather heavy clays, having high storage capacity, but for the most part they supply the water to crevices in the underlying rock rather than directly to wells. On the Eden and Siluro-Devonian shales the residual materials supply small quantities of water directly to springs and wells. On the Garrard sandstone member of the Eden

and on the Waverly shale the residual materials consist chiefly of sand, and they absorb considerable moisture, which readily sinks into the underlying rock.

Narrow strips of alluvium, in some places more than 50 feet thick, consisting of coarse sand containing layers of chert pebbles, are found along Kentucky River. The alluvium supplies abundant water for springs. A well sunk into it across the river from Camp Nelson obtained water at a depth of 50 feet.

CONSOLIDATED MATERIALS.

The Highbridge limestone reaches its maximum thickness of 400 feet in the northern part of the county across the river from Camp Nelson, and its upper layers are found near the top of the Kentucky gorge. It is exposed along the northern line of the county to a point about 2 miles above Camp Nelson and along Dix River nearly to the head of the gorge. Some excellent springs are found in this limestone along Kentucky River, and it might also yield water for shallow wells in the bottom of the gorge. On the upland, where it is covered by younger formations, it will yield no fresh water, but salt and salt-sulphur water can be obtained in it in some places.

The Lexington limestone is found in the Kentucky gorge above the Highbridge, and it forms the bottom of the gorge from the eastern end of the Highbridge exposure to the northeast corner of the county. It is also exposed along Dix River, in the valleys of Sugar and Paint Lick creeks, and over a large part of the upland in the western part of the county. This formation supplies water for springs along Kentucky River and in various places where exposed on the upland. Shallow wells on the upland also usually obtain an abundant supply of hard water, but deep wells drilled in it obtain highly mineralized salt and salt-sulphur waters.

The Winchester limestone forms part of the valley slopes in the northeastern part of the county and is exposed in a narrow band bordering the upland areas of the Lexington. Where it forms the surface rock it furnishes moderate quantities of hard water, but below the level of the surface streams and where it is covered by younger geologic formations its waters, as a rule, contain salt or salt and sulphur.

The Eden shale is exposed over a large area in the northeastern part of Garrard County and extends in a narrow band along the eastern edge of the Winchester limestone from about a mile east of Camp Dick Robinson southward to Dix River. The shale member of this formation yields small quantities of water to springs and shallow wells, but none to deep wells. The sandstone member also is in most places rather a poor water bearer, yielding little water except in localities where it is exposed at the surface. In the east-

ern part of the county, however, some of the more sandy layers furnish considerable water for springs and shallow wells.

The Maysville and Richmond formations are exposed over a large area between the northern edge of the mountains and a sinuous line drawn from Paint Lick to Camp Dick Robinson, and they are seen also in the valleys of some of the streams in the southern part of the county. They include nearly 200 feet of interbedded limestones and shales and about 100 feet of sandy limestones and shales. It seems possible that the sandy shales and possibly some of the upper beds of limestone belong to the Richmond formation. In the south-central part of the county the limestones of the Maysville are in many places very pure and the beds are unusually thick. They contain many subsurface channels, which afford favorable conditions for underground water, springs are numerous, and shallow wells are uniformly successful. The water of some of the deeper wells is, however, brackish or sulphurous.

The rocks of the Richmond formation are more shaly than those of the Maysville, and underground water conditions are less favorable, but springs and wells deriving water from them nevertheless yield ample supplies for farm use.

The Panola formation is exposed in a narrow band on the northern edge of the mountainous district and along some of the streams within it, and it occupies areas of considerable size west of the mountains. The shales of the Panola yield little water, but the limestone layers carry large quantities of water containing lime, magnesia, and other inorganic material.

The Ohio shale forms a narrow belt along the mountainous area and appears on a few isolated hills in the southwestern part of the county. This rock is generally traversed by joints which admit large quantities of water, and consequently numerous springs and shallow wells are supplied by it. The water in this formation is everywhere highly mineralized—alum water, chalybeate water, and sulphur being the most common types furnished by it.

The Waverly shale occupies the tops of the mountains in the southeastern part of the county. It has a maximum thickness exceeding 300 feet. The shale beds of the Waverly contain very little water, but the sandstones which cap nearly all the hills contain abundant supplies of soft water, which emerges in springs at the top of the underlying shale.

The St. Peter sandstone underlies the entire county and will furnish flowing wells in the lower part of Dix River gorge and in the gorge of Kentucky River north of the large fault. Here, as elsewhere in the region, the water of the St. Peter would be of such quality as to unfit it for ordinary purposes.

STRUCTURAL FEATURES.

The only important structural features exhibited by the rocks of Garrard County are the faults which occur in the northern and southern areas. The west end of the Kentucky River fault enters this county just south of Camp Nelson and extends southwestward several miles to the point at which it finally disappears. The displacement along this fault in Garrard County is less than 200 feet. The existence of two faults is shown by Campbell [a] in the southeastern part of the county. The maximum displacement of one of these faults has brought the Waverly shale into contact with the Panola formation. The presence of faults at the base of Burdetts Knob was noted by Owen [b] during the first geologic survey of the State.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Springs and dug or drilled wells form the principal sources of water supply for all domestic purposes in Garrard County. Springs are everywhere numerous, and they present considerable variety in composition. Soft water is reported in the vicinity of Point Leavell and Buckeye and at various places in the mountains; sulphur, chalybeate, epsom, and alum springs are common along the northern side of the mountains, and an alum spring occurs at the foot of Burdetts Knob. Springs of ordinary hard water are found in the northern and central parts of the county, and in the southern part of the county are some magnesian springs.

Sufficient water for a farm is as a rule obtained by dug wells less than 35 feet deep. In the western part of the county and near Paint Lick, Hyattsville, and Cartersville are a number of drilled wells ranging in depth from 60 to 100 feet. Near Cartersville drilled wells obtain sulphur water at depths of 25 to 50 feet. At Lancaster a drilled well sunk to a depth of 1,100 feet in an effort to procure a supply for the city obtained a small supply of fresh water near the surface and a large flow of salt-sulphur water at a depth of several hundred feet. The supply of Lancaster is now taken from a small stream which receives no objectionable drainage, and the water is very satisfactory, but considerable water is still used from shallow wells. It is doubtful if any of the well water is as pure as the city supply.

GRANT COUNTY.

SURFACE FEATURES.

Grant County is in the north-central part of the Blue Grass region. A narrow ridge, known as "Dry Ridge," with a maximum altitude of somewhat more than 950 feet, crosses the county from north to south

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.
[b] Owen, David Dale, Third Rept., Geol. Survey Kentucky, 1877.

and forms the divide between the tributaries of Eagle Creek and those of Licking River. The divides between the smaller streams are as a rule somewhat lower, but have a nearly uniform height, which represents the approximate level of the plateau which has been dissected. The streams all flow in narrow steep-sided valleys which have been carved in the plateau.

Crooked, Fox, and Grassy creeks, tributaries of Licking River, receive practically all the drainage of the area east of Dry Ridge. Eagle Creek, which crosses the western edge of the county, receives the drainage of its western half. Its principal tributaries in Grant County are Tenmile, Clarks, and Grassy creeks.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

Residual soil formed by the breaking up of the underlying rock covers the surface of the county. Near the northern end of the county, where the original rock contained many limestone layers, the soil approaches a loam in texture, but farther south, where shales predominated, the decomposition product is a heavy clay. In but few places is the residual clay more than 3 or 4 feet thick, and in many localities it is only a few inches thick.

Small patches of alluvium occur along all the large streams, but it is for the most part coarse material which was derived from the decomposition of the rocks on the slopes. A rock terrace along Eagle Creek is covered by a thin deposit of sandy alluvium.

Both the alluvium and the residual clay store considerable water and supply it gradually to the underlying rock, but they yield little water directly to wells. An exception to this rule is found where these unconsolidated materials rest on dense shale, for in such places the water is obtained directly from the loose material or from its plane of contact with the underlying rock.

CONSOLIDATED MATERIALS.

The Winchester limestone is exposed in the valleys of Eagle Creek and several small streams, and where it is at the surface it generally furnishes good supplies of hard water. In the bottoms of the valleys, however, wells in this formation obtain a brackish sulphur water, and on the upland, where it might be reached by drilling deep wells, its waters would be salt or salt-sulphur in character.

The Eden shale is exposed over a small area of the upland near the southern end of the county and on the slopes of all the principal streams. Here, as elsewhere in the Blue Grass region, this formation affords practically no water, except near the surface where small cracks have formed in the rock. Moreover, the soil above the shale is so dense that it yields little water. For this reason springs are

few and small and wells are not very successful in the areas of its outcrop.

The surface rocks over the greater part of the upland belong to the Maysville formation. The highest rocks of this formation that are exposed in the county are the heavy beds of limestone found north of Crittenden; south of Crittenden the lower and more shaly beds appear at the surface. The limestones of the Maysville near the northern end of the county favor the formation of underground channels whose presence is indicated by small sink holes. Farther south the rocks contain a much larger proportion of shale, and the underground channels are small. The soil over the more shaly areas affords but little water to the underlying rock, and consequently the underground supplies are limited. The water from these rocks is as a rule hard.

The Lexington and Highbridge limestones and the St. Peter sandstone might be reached by deep wells, but they would afford only salt or salt-sulphur waters. The water in the St. Peter is under sufficient head to rise to a height of nearly 600 feet above sea level, but this head would give flowing wells, if at all, only in the lowest part of the valley of Eagle Creek.

WATER FOR DOMESTIC AND INDUSTRIAL SUPPLIES.

The springs of Grant County are nearly all small, and some of them fail in dry weather. The only important mineral spring is Gum Lick Spring, in the southeastern part of the county, which supplies a good quality of salt-sulphur water. This spring was formerly visited by many persons who carried the water away for drinking.

Few dug wells in Grant County are more than 35 feet deep, and in dry weather they yield very little water. None of the drilled wells sunk in this county have been successful. At Williamstown an attempt was made to procure water for the city by drilling a deep well; no fresh water was found, but strong sulphur water was encountered between 700 and 790 feet below the surface.

Cisterns form the principal source of supply for domestic use, both in the towns and on farms. In a few localities where the Eden shale forms the surface rock cistern water is also used for stock. The city of Williamstown depends upon cisterns and hand engines for fire protection. The cisterns are located at various points along the main streets and are filled with water collected from the roofs of warehouses, stores, and churches.

HARRISON COUNTY.

SURFACE FEATURES.

Harrison County is in the east-central part of the Blue Grass region. A strip of country several miles wide, bordering the South

Fork of Licking River, has a gently rolling surface, with shallow valleys and rounded divides; but on the east and west of this area of slight relief the topography is rugged, the surface exhibiting steep-sided valleys separated by narrow divides. Rock terraces which lie slightly below the level of the upland border Licking River and its South Fork, and other terraces just above the level of these streams were observed at several localities.

Licking River forms part of the eastern boundary of the county, and the South Fork of the Licking flows northward through the center of it. Beaver Creek is the only large tributary of Licking River in this county. The greater part of the drainage is to the South Fork, which receives a number of large tributaries, the most important being Coopers Run, Grays Run, and Townsend, Twin, Crooked, and Indian creeks.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soils of Harrison County consist of loams on the areas of Lexington and Winchester limestones and clays on the Eden shale. The loams have an average thickness of about 3 feet, but the clays are in most places thin. These soils yield water only where they rest on dense shales.

A deposit of sandy alluvium, 10 to 20 feet thick, is found in many places on the rock terraces bordering the river and supplies an abundance of water for shallow wells. On the upper terrace are narrow deposits of the sandy alluvium belonging to the Irvine formation, which furnish small quantities of water in some localities; but the Irvine is not, as a rule, an important water-bearer.

CONSOLIDATED MATERIALS.

The Lexington limestone is exposed along the valleys of Licking River and its South Fork and over much of the area of rolling topography of the upland, and where it forms the surface rock it yields an abundance of water for springs and wells. Where it is reached below the levels of the surface drainage, however, it may supply salt-sulphur waters, such as are obtained by many of the drilled wells in this formation.

The Winchester limestone is exposed in a narrow band bordering the Lexington outcrops and furnishes moderate quantities of hard water. In the southwestern part of the county this limestone supplies some salt-sulphur water in springs and shallow wells. A well sunk near Smitsonville obtained a weak flow of sulphur water in this formation. The water rises about 4 feet above the surface, and the well yields less than 1 gallon per minute.

The Eden shale appears at the surface on the upland near the western boundary of the county, where it occupies a strip nearly 10 miles wide, and also on the divide between Licking River and its South Fork. It supplies small quantities of water for springs and shallow wells, but none for deep wells.

The Highbridge limestone is not exposed in Harrison County, and wells sunk to it would probably obtain only highly mineralized water.

Wells drilled to the St. Peter sandstone would probably procure flowing water in some parts of the valley of the South Fork of the Licking, but, as elsewhere in the region, the quality of the water would unfit it for ordinary uses.

DOMESTIC WATER SUPPLIES.

Dug or drilled wells and cisterns are used to obtain water for domestic purposes in this county. Few of the shallow wells exceed 35 feet in depth, and the amount of water which they yield depends on the nature of the rock in which they are dug. Drilled wells which yield water enough for a farm are common in many localities. The quality of the water varies with the depth of the well, many of the shallower wells obtaining hard water and the deeper wells sulphur water. The depth to the sulphur water varies, however, with the location of the wells, being about 50 feet in the valleys and over 100 feet on the hills. In areas where the Eden shale forms the surface rock cisterns form the principal source of supply.

HENRY COUNTY.

SURFACE FEATURES.

Henry County lies near the western edge of the Blue Grass region, south of Kentucky River, whose gorge here presents two steep slopes separated by a rock terrace at an elevation of about 500 feet above sea level. Near the Kentucky gorge the surface of the upland is deeply dissected by many small streams and is practically all reduced to slopes. Most of the divides are but a few rods wide, and the intervening valleys are, as a rule, narrow and steep sided. A few miles back from the Kentucky the surface is gently rolling, with shallow valleys and rounded divides, and topography of this type prevails throughout a large part of the county. The range in altitude within the county is about 200 feet.

Nearly all of the drainage of Henry County passes into Kentucky River, which receives the waters of three streams of considerable size—Mill, Sixmile, and Drennon creeks—and of many small tributaries. Streams flowing to Salt River drain a small area near the southern boundary of the county, and the drainage of an area along the western boundary of the county enters Harrods Creek and Little Kentucky River, whose principal tributary in Henry County is Sulphur Creek.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soils of Henry County are, as a rule, heavy clays on the areas underlain by Eden shale, but on the other formations they are lighter and in some localities they are loamlike in texture. The soils yield moderate quantities of water only where they rest on the Eden shale.

Strips of alluvium, consisting of sand containing some layers of gravel, occur in the gorge of Kentucky River, and in some places a thin layer of alluvium also rests on the rock terrace which borders the river. It is evident that these isolated patches represent the eroded remnants of a deposit which once covered the terrace. The alluvium of the Kentucky gorge supplies some good springs along the river, and it would doubtless yield an abundance of water for wells. Some of the springs at Drennon Springs rise through this alluvium, but the water is probably derived from the Lexington or Winchester limestone.

CONSOLIDATED MATERIALS.

The Lexington limestone underlies the terrace which borders Kentucky River and is exposed in the gorge of the river from the Franklin County line to Drennon Springs, occupying the lower parts of the gorge and rising to about the level of the terrace along the valley for some distance north of the southern line of the county. It contains numerous sink holes and supplies several large springs of hard water. A short distance back from the river this limestone dips under the younger formations, and where it is thus covered it will yield no fresh water. In some places in this county both the Lexington and Highbridge limestones yield salt-sulphur waters when penetrated by deep wells.

The Winchester limestone lies above the Lexington and extends a short distance farther down the stream, but it is exposed only in the gorge of the Kentucky and the lower parts of some of its tributaries and does not rise to the level of the upland. In the areas of its outcrop it yields moderate quantities of hard water, but elsewhere in the county it may yield mineral waters.

The Eden shale outcrops on a small area of the upland near Kentucky River and extends some distance back from the river along the principal streams. Where it lies at the surface it supplies moderate quantities of water for springs and shallow wells, but over a large part of the county it is buried beneath the rocks of the Maysville formation and will yield practically no water.

The Maysville and Richmond formations are found over a large part of the upland, underlying nearly all of the area of rolling topography, and they supply water for many perennial springs. Sufficient

water for a farm can generally be obtained by wells 25 to 50 feet deep. A few unsuccessful deep wells have been drilled in Henry County.

Near the western line of the county is a narrow ridge which is underlain by the blue shales and yellow magnesian limestones of the Panola formation. Because of the small area of its outcrop the Panola is not important as a source of underground water.

The St. Peter sandstone will supply flowing wells in the gorge of Kentucky River. The water will be of the highly mineralized type usual in this formation.

STRUCTURAL FEATURES.

The rocks of Henry have a general northwesterly dip of a few feet to the mile, which was produced by the arching that formed the Jessamine dome. The uplift appears not to have been accompanied by any great amount of local disturbance in this county, though some minor folds and displacements have been observed at Drennon Springs.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Henry County has a number of "never-failing" springs, but few of them are large. Springs are commonly used for stock, but some of them also serve household purposes. At Drennon Springs, an important health resort located on Kentucky River, the most important are the sulphur and salt-sulphur springs. Both black and white sulphur springs are reported. At Eminence a chalybeate spring supplies a moderate quantity of water.

Most of the wells of Henry County are shallow, ranging from 20 to 35 feet in depth. Such wells form a satisfactory source of water for domestic use only when they are carefully guarded from pollution. Considerable water is used from these shallow wells both in the towns and in the country. The few deep wells drilled in Henry County have not been very successful.

Both Eminence and Newcastle could procure surface water for municipal supplies by constructing reservoirs on small streams, but underground supplies of suitable quality are not available. This should not, however, be considered a misfortune, for a careful comparison of the best surface and underground supplies of the region indicates that the surface waters are more desirable than those derived from either springs or wells.

JESSAMINE COUNTY.

SURFACE FEATURES.

Jessamine County lies in the great bend of Kentucky River near the southern border of the Blue Grass region. Its surface is gently rolling except near the southern and western boundaries, where the

Kentucky and its tributaries have cut deep channels, and altitudes range from less than 500 feet above sea level in the Kentucky gorge to over 1,000 feet in the highest parts of the upland. Where the streams cross the limestone formations the walls of their valleys are generally nearly perpendicular, but where they flow through shales and shaly limestones the slopes are gentler.

The drainage of the county reaches Kentucky River through Hickman and Jessamine creeks and several smaller streams, and a small area in the northern part of the county is drained by the southern branches of Clear Creek, which unites with the Kentucky in Woodford County. All the streams flow in deep narrow gorges and have very high gradients, making the descent from the upland to the river within a few miles.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The upland of Jessamine County is covered by a mantle of yellow or brownish-red unconsolidated material which has been formed by the decomposition of the underlying rock. On limestone areas this material has the texture of a loam, but on areas where the original rock contained a large proportion of shale it is chiefly a dense clay. Although the residual clay has in some places a thickness of 20 feet or even more, its average thickness probably does not exceed 5 or 6 feet. The soils furnish little water directly to wells, but they have a high storage capacity and feed their supply of water slowly to the crevices in the underlying rock. The loam stores less water than the clay, but it generally contains some free water which is available for the underground channels.

Sandy alluvium occurs in narrow strips along Kentucky River and yields water for numerous springs. It would doubtless also furnish an abundance of water for wells.

CONSOLIDATED MATERIALS.

The apex of the Jessamine dome is located in this county, and the oldest rocks of the region are exposed at Camp Nelson, where Kentucky River passes near the crest of the dome. These rocks belong to the lowest division of the Highbridge limestone. The entire thickness of the Highbridge in Jessamine County is about 400 feet, and the exposures are restricted to the valleys of Kentucky River and its principal tributaries. The Highbridge furnishes large quantities of hard water to springs and to most of the shallow wells, but deep wells and a few of the shallow ones obtain either salt or salt-sulphur water.

The Lexington limestone forms the surface rock over the greater part of the county, overlying the Highbridge limestone without

apparent unconformity. The maximum thickness of this limestone is about 200 feet, but the thickness over a large part of Jessamine County probably falls much below the maximum. Where it outcrops at the surface it contains many underground channels and large quantities of hard water. Nearly all of the springs and shallow wells over a large part of the county north of Hickman Creek are supplied with water from this limestone. The wells which penetrate this formation below the level of the surface drainage as a rule find salt or salt-sulphur waters.

The Winchester limestone is exposed along the Kentucky River gorge and on the south side of Hickman Creek, in the southern part of the county, and occupies a long narrow strip and several isolated patches on the upland in the northeastern part of the county. Where it is at the surface it yields moderate quantities of hard water to springs and shallow wells. In the southern part of the county it would be penetrated only by deep wells which would be apt to obtain salt and sulphur waters.

The Eden shale occurs over a large part of the upland between Hickman Creek and Kentucky River, and appears also as a small isolated patch in the northeastern part of the county. In this county the upper portion of the Eden consists of sandy shales and sandstones, which were mapped as the Garrard sandstone by the early workers of the Kentucky Geological Survey. The shale beds of the Eden furnish little water, but some of the limestones contain crevices which supply small quantities of moderately hard water for wells and springs. Some water is also obtained at the contact of the residual clay with the underlying rock. The Garrard sandstone member of the Eden is in most places not porous enough to yield much water, but the residual soil formed from it locally furnishes considerable soft water for both wells and springs.

The St. Peter sandstone will supply flowing wells in the valleys of the large streams north of the Kentucky River fault in this county. On the upland the water will not reach the surface, as the head is only sufficient to cause the water to reach an altitude of about 590 feet above sea level. South of the Kentucky River fault few wells have been drilled to the St. Peter, and definite information as to the head of the water encountered by these wells is not available. It appears probable that the faulting has produced a displacement of the St. Peter which might interrupt the movement of the water.

STRUCTURAL FEATURES.

The only marked structural feature in this county is the Kentucky River fault, which extends along the valley of Hickman Creek, in the southern part of the county. There are really two faults, one enter-

ing near the southeast corner of the county and extending southwestward nearly to its western boundary, and another beginning a few miles south of this first fault and running southwestward into Garrard County. The maximum displacement along these faults is probably about 400 feet. At one point near the southeast corner of the county it was sufficient to bring the Garrard sandstone member of the Eden shale into contact with the Highbridge limestone.

UNDERGROUND DRAINAGE.

The presence of caverns along Kentucky River and numerous sink holes and springs on the upland indicate that the underground drainage is very extensive. Some of the sink holes are several acres in extent, and many of the springs give rise to streams of considerable size. The large springs, as a rule, emerge at the heads of small gullies rather than along the river. This peculiar location of the springs is explained by the fact that the gully represents merely the portion of the underground channel where the roof has fallen. Sinking Creek, in the northeastern part of the county, affords an excellent example of a surface stream which enters an underground passage.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Springs and dug or drilled wells supply water for domestic and industrial purposes. One of the largest of the many large springs is Overstreet's, which supplies water enough to run a small mill, and another large spring is utilized at Union Mills.

Dug wells are numerous, but they are not extensively used. Drilled wells have been successful in some localities, but a number of dry holes are reported at Nicholasville, Keene, and Wilmore. Many of the drilled wells have found sulphur water at depths of 50 feet or more, but the amount of sulphur is commonly not great enough to render the water unfit for domestic use. At Union Mills a well sunk in the Highbridge limestone to a depth of 283 feet obtained a little fresh water between 30 and 40 feet below the surface and several supplies of salt-sulphur water at greater depths. At 200 feet the driller reported a stream of this water which was strong enough to remove the pulverized rock produced in drilling.

Nicholasville has the only municipal supply in the county. The water, which is taken from wells located on the edge of a reservoir, probably comes in part from the reservoir. The wells were sunk because some of the consumers objected to the surface water, but the installation of a filtering plant would probably have been a greater improvement.

KENTON COUNTY.

SURFACE FEATURES.

Kentón County occupies a long, narrow area in the northern part of the Blue Grass region, extending northward to Ohio River and eastward to Licking River. Its surface is a plateau which has been deeply trenched by the tributaries of the Ohio and Licking rivers, and the upland areas, which are comparatively level, rise to a height of 900 feet above tide, or more than 500 feet above the Ohio.

The northwestern corner of the county drains into the Ohio through Dry Creek and several other small streams. Bank Lick Creek, which flows diagonally across the northern part of the county and enters Licking River at Latonia, receives the draniage of the central part of the county, and the southern end of the area drains to Licking River through Cruises and Grassy creeks and several smaller streams. All of these streams have high gradients, most of them making the descent from the uplands to the rivers within a few miles.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

A thin mantle of unconsolidated material covers the rock formations. Near the Ohio this loose material is of glacial age and consists in part of sand and in part of clay, containing fragments of limestone and other rocks. Resting on the glacial drift are 2 or 3 feet of loess-like silt, which is also of glacial age. On the upland the glacial drift has an average thickness of less than 10 feet and a maximum thickness of about 20 feet. In the Licking Valley, near Latonia, the drift appears to be somewhat thicker than on the upland. Although the sands of the glacial drift are of small extent, they would probably yield some water for shallow wells at a few localities. The bowlder clay and the overlying silt do not yield water directly to wells, but they are sufficiently porous to absorb some water which they feed to the underlying rocks.

South of the area of glacial drift the unconsolidated material consists of yellowish or reddish clay, in most places less than 5 feet thick, derived from the underlying rock. This clay is porous enough to absorb considerable moisture, but it does not afford sufficient water at any one place to supply a well.

The alluvium of Kenton County consists of terraces of sand and gravel along Ohio River, which rise to a maximum height of about 550 feet above sea level. The thickness of these and similar deposits along Licking River is from 80 to 120 feet, and they yield large quantities of water at depths of 60 to 110 feet. The water is moderately hard, and in the vicinity of Covington contains some sulphur. This

sulphur may be supplied by the decomposition of the organic matter in the alluvium or by the sulphur water which comes from the rocks which form the floor of the valley. The alluvium in the Licking Valley should have a thickness of 30 to 50 feet, but few wells have been sunk in this deposit and its exact thickness is unknown. In other parts of the Blue Grass region similar deposits yield large quantities of moderately hard water.

CONSOLIDATED MATERIALS.

The oldest rocks in Kenton County outcrop in the channel of the Ohio between Covington and Ludlow. The exposure consists of about 50 feet of interbedded limestones and shales, at the top of which is a wave-formed bed of limestone containing fragments derived from the underlying rock. These interbedded limestones and shales are believed by E. O. Ulrich to be the equivalents of the lower part of the Lexington limestone. Over all the upland portion of the county the Lexington and Highbridge limestones are deeply covered by younger formations, and under such conditions they supply only salt water, which will in some places be sulphurous.

Above the Lexington limestone and occupying the lower slopes of the valleys are about 300 feet of dark-colored shale belonging to the Eden formation. This shale supplies practically no water for wells, though small quantities of water are in some places obtained from the talus which rests on the valley slopes.

The upland is underlain by rocks belonging to the Maysville formation. In the southwestern and northern parts of the county these rocks are shaly and supply only small quantities of water, but elsewhere the uplands are capped by limestone beds of the formation, which furnish ample supplies of water for farm use. The numerous springs found on the upland derive their water from these limestone beds. Along Ohio River the springs emerge near the tops of the bluffs, where the limestone layers rest on beds of shale.

In this county the St. Peter sandstone lies 800 or 900 feet below the surface in the Ohio Valley and 1,300 to 1,400 feet below the surface of the uplands. It yields a strong salt-sulphur water, which will rise to the surface in places having an altitude of 590 to 600 feet above sea level. Wells drilled in this formation at Covington and Latonia obtained good flows.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Dug wells are still used extensively in Kenton County; in many of them the supply is augmented by permitting rain water from the roof to flow into the well. In some instances water is hauled from a nearby spring and poured into the well. Cisterns are an important

source of water for domestic purposes, and they are gradually supplanting the wells.

No deep wells have been drilled on the upland, but driven and drilled wells are numerous in the Ohio Valley. These wells range in depth from about 80 to 120 feet and procure large supplies of water for domestic and industrial uses. Here, as elsewhere in the valley of the Ohio, the water near the river is apt to contain less inorganic matter than at some distance from the stream. Water for city supplies is obtained from Ohio River and is regarded as satisfactory for most purposes.

MADISON COUNTY.

SURFACE FEATURES.

Madison County is situated on the south side of Kentucky River in the extreme southern part of the Blue Grass region. A large part of the county is a broad plateau, deeply cut by narrow, steep-sided valleys near Kentucky River and along the western boundary. In the central part of the county is a belt, 5 to 10 miles wide, in which stream valleys are shallow and the surface is gently rolling. The extreme southern part of the county includes a rugged area, characterized by irregular ridges rising nearly 500 feet above the level of the plateau and separated by broad, level-floored valleys. The slopes of many of these mountains are so precipitous that their ascent is very difficult.

The drainage of Madison County goes to augment Kentucky River. Red River, which receives the drainage of the southeastern part of the county, flows eastward and joins Station Camp Creek, a tributary of the Kentucky, in Estill County. Paint Lick, which flows along the western boundary of the county, receives the drainage of a narrow strip near that boundary. Silver and Tates creeks drain the western and Otter and Muddy creeks the eastern part of the county.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The unconsolidated materials in Madison County consist of rather dense clays, derived from the limestone and shale formations; of loams, derived from the Garrard sandstone member of the Eden shale and the sandstone of the Waverly shale; and of alluvial sands and gravels in the gorge of Kentucky River.

The residual soils furnish a small amount of water for springs and shallow wells on the areas underlain by shale, but elsewhere they furnish practically no water. The alluvial sands and gravels of the Kentucky gorge furnish an abundance of water for springs along the river bank, and they would doubtless also furnish water for wells.

CONSOLIDATED MATERIALS.

The Highbridge limestone is exposed along Kentucky River in the four bends which lie north of the Kentucky River fault. Although the upper part of this limestone lies near the top of the gorge, it does not extend out upon the upland. The Lexington limestone is exposed in the same localities as the Highbridge, and it forms also the lower part of the gorge from the last crossing of the fault above Boone Ferry to the northwestern corner of the county, and the lower parts of the valleys of Silver Creek and Paint Lick to the vicinity of Cartersburg. Both the Highbridge and Lexington limestones supply considerable water to springs and shallow wells in the valleys of the streams; but on the uplands they are buried by younger formations, and under such conditions they will yield only salt or salt-sulphur water.

The Winchester limestone is exposed in a narrow area surrounding the Lexington, but it does not rise to the level of the upland except near Kentucky River. It furnishes moderate quantities of hard water where it is exposed at the surface, but where it underlies younger formations its water is generally brackish and somewhat sulphurous.

Outside the area of the Winchester limestone is the Eden shale, its upper portion including 70 to 130 feet of sandy shales and sandstone—the Garrard sandstone member. The lower part of the Eden outcrops in the valleys of the streams in the northern and western parts of the county, and the Garrard sandstone member reaches the level of the upland in the same areas. The Eden shale supplies small quantities of water for springs and shallow wells, but deep wells do not as a rule obtain water in this formation. The Garrard sandstone member supplies more water than the shale member, but it contains so large a proportion of clay that it is unimportant as a water horizon.

The Maysville formation underlies a large part of the rolling surface of the upland. East of Richmond some of the higher hills are capped by about 50 feet of green sandy shales, which may represent the Richmond formation. The limestone beds of the Maysville present favorable conditions for the occurrence of moderate quantities of water, but conditions somewhat less favorable are afforded by the Richmond rocks. A number of good-sized springs occur in the limestones of the Maysville, and shallow wells are ordinarily successful in both the Maysville and Richmond formations.

The blue shales and heavy-bedded yellow limestones of the Panola formation, as mapped by Campbell,[a] occupy considerable areas in the eastern and southern parts of the county. The shales of the lower part

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

of the Panola supply practically no water, but the limestone beds generally furnish enough water for domestic use. As the limestones of this formation are magnesian, much of the water contains magnesia.

The Ohio shale, which in this county has a thickness of 110 to 150 feet, is exposed in many places above the limestones of the Panola formation and it generally rims the mountains. It supplies an abundance of highly mineralized water for springs and shallow wells, the most common types being alum, sulphur, and chalybeate waters.

The sandy beds at the top of the Waverly shale, which caps the mountains in the southern part of the county, yield an abundance of soft water, and numerous springs emerge from these sandstones where they rest on the shale beds.

Along the southern line of the county is a small and unimportant area of later Mississippian limestone.

The St. Peter sandstone underlies the entire county and will probably supply flowing wells in the gorge of Kentucky River north of the large fault. It is possible that a flow might also be obtained in some of the deeper stream valleys south of the fault. The water from this formation is so highly charged with salt and sulphur that it is unfit for ordinary uses.

STRUCTURAL FEATURES.

The rocks of Madison County dip gently toward the southeast and present no important structural features except the faults which have produced displacements of the Ordovician formations. The major fault of the region—the Kentucky River fault—crosses the northern part of the county. Kentucky River crosses this fault eight times on the northern boundary of the county, and thus the fault plane is alternately in Madison and Clark counties. The maximum displacement in Madison County, as given by Campbell[a] is 400 feet, and this has brought the Highbridge limestone to the same altitude as the Garrard sandstone member of the Eden shale. The Richmond folio shows also two small faults in the southern part of the county which are roughly parallel to the direction of the Kentucky River fault. East of Richmond is a fault which is almost at right angles to the other faults of the region. None of these faults are of great magnitude, the maximum displacement having brought the Ohio shale into contact with the limestone of the Maysville formation.

WATER FOR DOMESTIC AND INDUSTRIAL USES.

Both surface and underground waters are used in Madison County.

Richmond obtains its water supply from a small stream. Attempts to get water by drilling wells in the city have not been successful.

[a] Campbell, M. R., Richmond folio (No. 46), Geol. Atlas U. S., U. S. Geol. Survey, 1898.

One well, sunk to a depth of nearly 1,800 feet, is said to have obtained water highly charged with sulphur.

Many good springs are found in various parts of the county. Between Kentucky River and Richmond and for some distance eastward most of the springs yield moderately hard water. Sulphur springs occur at Boonesboro and at various points in the area of the Ohio shale, and this shale also furnishes springs of epsom, alum, and chalybeate water. Springs of soft (freestone) water are found near Elliston and at various points in the mountains, and Berea College has an excellent water supply derived from such springs.

Dug wells 20 to 35 feet deep are common on the upland, and an ordinary well affords sufficient water for a household. Besides the wells at Richmond, a number of wells have been drilled at Berea and Wallacetown. Few of these wells exceed 50 feet in depth and most of them yield sulphur water. A few wells have been drilled in other parts of the county, but these as a rule have not found large supplies of fresh water.

MASON COUNTY.

SURFACE FEATURES.

This county borders Ohio River at the eastern edge of the Blue Grass region. The surface is a deeply dissected plateau, with a range of altitude exceeding 450 feet. The amount of dissection varies considerably, being greatest near the large streams and diminishing rapidly a short distance from these streams. In the southern part of the county variations in altitude are smaller and the slopes gentler, and another area of rolling topography occupies a strip several miles wide between Maysville and Germantown. In the Ohio Valley alluvial gravels form flat terraces which rise about 80 feet above the river.

The northern part of the county drains into Ohio River through Limestone Creek and a number of other small streams. The North Fork of Licking River, which flows westward through the central part of the county, receives the drainage of a wide area. Johnson Creek, a tributary of the Licking, receives several small tributaries from the southern part of the county.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The upland of Mason County is covered by a deposit of residual material varying in thickness from 6 to 8 feet and in character with the nature of the underlying rock. On sandy shales the material is a loam; on denser shales a heavy clay, and on the limestones clay or loam, as sand or clay were prominent constituents of the original rock. These residual materials furnish little water directly to wells, but they

store considerable moisture, which they feed slowly to crevices in the underlying rocks.

The terraces of the Ohio Valley consist of 80 to 120 feet of coarse sand and gravel. These deposits furnish an abundance of moderately hard water.

CONSOLIDATED MATERIALS.

The Winchester limestone is exposed at the foot of the bluff bordering the Ohio Valley from the Bracken County line southward beyond Maysville, along the North Fork of Licking River, and along some of the tributaries of both the Ohio and the Licking. Where it is exposed in the valleys of the streams it furnishes, as a rule, moderate quantities of hard water. Saline and sulphur springs are also found in this formation at several localities. No deep wells have been drilled in the Winchester on the upland, but it is quite certain such wells would not find fresh water.

The Eden shale forms a large part of the valleys of the principal streams and extends out upon the upland in the western part of the county. The formation is more sandy here than in the more northern counties, but it does not contain enough sand to be classed as a sandstone. It yields small quantities of hard water to both springs and shallow wells, but no water to deep wells.

The Maysville formation is most typically developed in this county. It forms the surface rock over large areas and is well exposed in the vicinity of Maysville, where the entire formation is represented. The limestones of the Maysville as a rule furnish an abundance of hard water for springs and shallow wells, and the drilled wells of the upland usually obtain water in these rocks.

The Richmond formation is at the surface over a small area extending from Ohio River east of Maysville to the southern line of the county. In this county the lower part of the Richmond consists of sandy shales with some thin beds of limestone; the upper part is generally more calcareous and contains a number of beds of limestone. The rocks of the Richmond supply less water than those of the Maysville formation, but the quantity is usually sufficient for farm use.

The tops of the highest ridges and hills in Mason County are capped by gray cherty limestones and blue shales belonging to the Panola formation. Where the shales are at the surface this formation yields only a small supply of water, but where the limestones are exposed enough water for a farm can usually be obtained.

The Lexington and Highbridge limestones and the St. Peter sandstone are in this county buried beneath younger formations and will yield only salt or salt-sulphur water. The well-known "Blue Lick" water of the St. Peter should be reached at a depth of less than 1,000

feet in the Ohio Valley, and it would flow at the surface. Flows could also be obtained in the valleys of the smaller streams where the altitude of the surface does not exceed 580 feet above sea level.

MERCER COUNTY.

SURFACE FEATURES.

Mercer County is located near the southwest corner of the Blue Grass region, on the west side of Kentucky and Dix rivers, which here flow in narrow gorges with perpendicular walls. The difference between the altitude of the Kentucky and the higher parts of the upland is more than 400 feet. Near the rivers the upland is deeply trenched by a number of small streams, but a few miles back the slopes become gentler and the variations in altitude smaller, as a rule not exceeding 100 to 200 feet. In the western part of the county the surface is more rugged, the slopes being moderately steep and differences in altitude amounting to 200 feet or more.

The eastern edge of the county drains into Kentucky and Dix rivers through a number of small streams less than 5 miles long. The principal stream within the county is Salt River, which, flowing northward, separates the area of low relief from that of more rugged topography. This river, which unites with the Ohio south of Louisville, flows within a few miles of the Kentucky. In this county the divide between the tributaries of the two streams is in few places more than 4 miles from the Kentucky. The southwestern part of the county is drained by Chaplin River, the chief tributary of Salt River in the Blue Grass region.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIAL.

The upland portion of the county is covered with a mantle of residual material, which varies in texture from a loam to a clay. The loams occur where the material was derived from limestone and the clay where the original rock contained a large amount of shale. The residual materials furnish very little water for either springs or wells, although in general the water conditions are more favorable in localities where the soils are loamy than where clays are found, and in a few places, as at Harrodsburg, the loam may supply considerable water during a wet season.

Narrow strips of sandy alluvium, which supply large quantities of water to springs on the river bank, occupy the wider parts of the gorge in the Kentucky River valley. The few wells that have been sunk in this formation have obtained an abundance of water.

CONSOLIDATED MATERIALS.

The Highbridge limestone outcrops in the gorges of Kentucky and Dix rivers and along the lower courses of some of the tributaries of these streams, but it does not reach the level of the upland. Near Highbridge it is about 300 feet thick, but its northward dip carries its lower portion below the level of Kentucky River in this county, and at the northern boundary the thickness exposed does not exceed 150 feet. In the river gorges and in some of the creeks where it forms the surface rocks the Highbridge furnishes ordinary hard water for springs, but wells which penetrate it below the level of the surface streams as a rule encounter salt or sulphurous waters. On the upland this limestone lies from 150 to 500 feet below the surface, and wells sunk to it will not obtain fresh water.

The Lexington limestone outcrops along Kentucky and Dix rivers, forms the surface rock on the upland near these streams, and is exposed in the valleys of Chaplin and Salt rivers and over considerable areas east and northeast of Harrodsburg. Where it forms the surface rock it appears to afford conditions unusually favorable for underground water; springs are numerous, very few wells have been unsuccessful, and many of the wells obtain large supplies. Water encountered in this limestone below the level of the surface drainage is, as a rule, salt and may be sulphurous.

The Winchester limestone is found on the highest parts of the divide between Kentucky and Salt rivers, where it furnishes an abundance of hard water for springs and shallow wells, and it also yields small quantities of water for springs and shallow wells in the valleys of Chaplin and Salt rivers. Many of the wells that penetrate this limestone below drainage levels obtain salt-sulphur water. It is probable that some of the sulphur springs found in the county come from this formation.

The Eden shale outcrops on the divide west of Salt River, but it yields very little water and this only in small springs or shallow wells, which are apt to fail during dry weather.

Near the western edge of the county is a belt capped by rocks belonging to the Maysville formation, but they contain here so large an amount of shale that they yield little more water than the Eden shale. Near the northwestern part of the county, however, they furnish fair supplies for a number of shallow wells.

The St. Peter sandstone underlies the county at depths of from 700 feet in the gorge of Kentucky River to 1,100 feet or more on the upland, the depth being least near the southeast corner of the county and diminishing toward the north and west. This formation will yield flowing wells of salt-sulphur water in the gorges of Kentucky and Dix rivers and of some of the other streams at altitudes of less than 580 feet above sea level.

NICHOLAS COUNTY.

SURFACE FEATURES.

Nicholas County is situated in the east-central part of the Blue Grass region. Along its western side is a belt of gently rolling upland, with shallow valleys and rounded interstream spaces, but the rugged topography of the rest of the county shows differences in altitude amounting in many places to 200 to 300 feet, the areas of level land consisting of winding divides, as a rule, only a few rods wide.

Licking River, which flows along the east edge of the county, receives the drainage of a strip of land a few miles in width, but the drainage of the greater part of the county enters Hinkston Creek, a stream which forms part of the southern boundary. The streams of Nicholas County are all small—few of them exceeding 6 miles in length—and they flow in narrow V-shaped trenches whose slopes are in many places too steep for cultivation.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials of Nicholas County include heavy loams on the Lexington and Winchester limestones and heavy clays on rocks belonging to the Eden shale and the Maysville formations. These soils furnish little water to wells except where they are underlain by impervious rocks.

CONSOLIDATED MATERIALS.

The Lexington and Winchester limestones are exposed in the valley of Licking River and on the upland near the western edge of the county, and they underlie nearly all of the areas of rolling upland. In the western part of the county they furnish an abundance of hard water for springs and shallow wells; the Lexington, as a rule, yields somewhat more water than the Winchester, but sufficient water for a farm can be obtained from either formation. Wells sunk in these formations below the level of the surface streams are apt to find salt-sulphur waters.

The Eden shale forms the surface rock over a large part of the upland and furnishes small quantities of water for springs and shallow wells but none for deep wells. The water is moderately hard, but is entirely satisfactory for domestic use.

The Maysville formation is represented in Nicholas County by a series of interbedded limestones and shales which cap the higher hills in the south-central part of the county. The formation, as a rule, affords somewhat more favorable conditions for the occurrence of underground water than the underlying Eden shale, and in this

county it furnishes moderate quantities of hard water for springs and shallow wells.

The Highbridge limestone and the underlying St. Peter sandstone yield some salt-sulphur water for deep-drilled wells in this county. The St. Peter will supply flowing wells in the valley of Licking Creek, below Upper Blue Lick Springs, where the altitude of the river is 596 feet above sea level.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

The Upper and Lower Blue Lick Springs of Nicholas County furnish a large amount of excellent salt-sulphur water. Bottling works have been established at both of these springs and a great deal of the water is placed on the market. At the Lower Blue Lick Spring a hotel has been opened for the accommodation of those who prefer to use the water at the spring.

On the upland, springs are of moderate size and most of them yield hard water. In some localities they furnish water for domestic use, but ordinarily they are used only for stock.

Dug wells 15 to 30 feet in depth are common, but they are little used except during dry weather when other sources of supply fail. Drilled wells have been sunk at a few localities, but they have, as a rule, obtained water too highly mineralized for ordinary use.

Carlisle is the only city in the county large enough to warrant the installation of a public supply. Underground water suitable in quality and sufficient in quantity is not available for such purpose, but a surface supply might be obtained by constructing a reservoir on some of the small streams near the city. As none of these streams flow during dry weather, a large reservoir would be needed.

OLDHAM COUNTY.

SURFACE FEATURES.

Oldham County is in the western part of the Blue Grass region, and Ohio River flows along its border. In the southeastern part of the county the streams flow in shallow, gently sloping valleys, separated by rounded divides which in few places exceed 100 feet in height. Farther west the valleys are narrow and steep sided and the interstream spaces are for the most part flat. The relief increases toward Ohio River, and the descent from the upland to the river is in most places abrupt, the difference in altitude between the river and the upland amounting to more than 350 feet.

Southeast of La Grange the surface drains to Floyds Fork of Salt River, the principal tributaries of the stream in Oldham County being East, North, and Rodmans forks. Harrods Creek, the chief tributary of the Ohio in this county, heads in Henry County and flows southeastward, joining the Ohio below the Oldham County line. The Ohio

also receives several small tributaries in this county, the largest—Patton Creek—being less than 10 miles long.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The western half of the county is covered by a few feet of reddish till, containing numerous pebbles of chert and limestone, with occasional fragments of granitic rock; the eastern half is covered by a thin deposit of residual material, varying in texture from loam to clay. The residual materials are not important as a source of water for either wells or springs. The alluvium of the Ohio Valley will furnish an abundance of moderately hard water at depths of 60 to 100 feet, but, as many of the people who reside in the valley prefer cistern water, few wells have been sunk in this deposit.

CONSOLIDATED MATERIALS.

Rocks belonging to the Maysville and Richmond formations are exposed in the valleys of all the large streams and occupy considerable areas on the upland in the eastern and northern portions of the county. In the eastern part of the county these rocks supply numerous springs and shallow wells. Few of the wells and springs yield large quantities, but in many localities the springs do not fail even in the dryest weather. The most successful wells are less than 40 feet deep. The upper part of the Richmond formation in Oldham County comprises over 40 feet of heavy-bedded calcareous rock, resembling sandstone and containing many concretions.

The gray magnesian limestones of the Panola formation present very favorable conditions for the occurrence of underground water in Oldham County. Springs in this formation are numerous, the most important being the Anita and Royal Magnesian springs, and drilled wells obtain water at depths of 40 to 60 feet. The water is usually found at the top of the shale beds which underlie the limestones. The average yield of a single well is about 10 gallons a minute. The quality of the water is shown by the analysis of the water from Anita Spring. (See p. 211.)

The Eden shale will supply little water in Oldham County.

The Highbridge, Lexington, and Winchester limestones and the St. Peter sandstone are deeply buried in Oldham County. The limestone formations may furnish saline or saline-sulphur water when reached by deep wells. The St. Peter will supply flowing wells of salt-sulphur water in the Ohio Valley. A well drilled at La Grange about twenty years ago obtained a flow of slightly sulphurous saline water. The exact horizon from which the water was obtained is not known, but from the fact that the well was about 1,200 feet deep it seems probable that the water may come from either the Lexington or the Highbridge limestone.

OWEN COUNTY.

SURFACE FEATURES.

Owen County is in the west-central part of the Blue Grass region. Topographically, it comprises a gently rolling upland area in its central part, with broad, flat-topped divides and narrow, shallow valleys, and elsewhere more rugged areas, deeply trenched by narrow valleys separated by winding ridges. A narrow rock terrace extends along the valleys of Kentucky River and Eagle Creek, and at Gratz an abandoned channel of the Kentucky stands at about the same level as the rock terrace. This channel evidently represents the course of the Kentucky at the time of the formation of the terrace; in changing to its present course past Lockport the river evidently followed the channels of Sixmile Creek and some of its tributaries.

The Kentucky forms the western boundary of the county and receives all of the drainage, chiefly through Eagle, Clear, Severn, and Big Twin creeks. Eagle Creek, whose principal tributaries are Caney, Stephens, and Brush creeks, crosses the western edge of the county and forms the northern boundary.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soil of Owen County is chiefly clay, as a rule very thin on the Eden shale, but having an average thickness of $2\frac{1}{2}$ to 3 feet where rocks of the Maysville formation form the level areas of the upland. These soils are not important as a source of water.

The terrace along Kentucky River and Eagle Creek has in most places a thin coating of sandy alluvium, which should supply some water for shallow wells.

CONSOLIDATED MATERIALS.

The Lexington limestone is exposed in the gorge of Kentucky River from the Franklin County line to Drennon Springs, in Henry County. The Winchester limestone outcrops in the gorges of Kentucky River and Eagle Creek and extends a short distance back from these streams along their principal tributaries. Both of these limestones furnish hard water in a number of the streams, and saline springs emerge from them at several places in the southern part of the county. Over a large part of the county the Winchester, Lexington, and Highbridge limestones are deeply buried by younger formations and will not supply fresh water.

The Eden shale outcrops along the valleys of the principal streams and on the upland in the southern part of the county and furnishes small quantities of water for springs and for wells 30 to 35 feet deep.

These rocks are, however, too dense to yield water except near the surface.

Rocks belonging to the Maysville formation occupy a large part of the upland surface of the county and yield considerable moderately hard water for shallow wells—in most of the wells sufficient for a farm. The best springs in this formation are in the central part of the county, where the formation contains some heavy beds of limestone. Some of the best wells and springs of the Maysville formation are found near the city of Owenton, and the possibility of obtaining an underground supply for the city has been discussed. None of the wells in the vicinity are, however, strong enough to afford more than a small part of the water that would be needed for the municipal supply. Deep wells would doubtless obtain an abundance of water, but it would be too highly mineralized for ordinary use, and if a city supply is to be installed the water must be taken from a stream. One of the spring-fed branches near the city would probably furnish the most satisfactory supply of surface water.

Flowing wells of strong salt-sulphur water may be obtained from the St. Peter sandstone in the gorge of Kentucky River, in the valley of Eagle Creek where it borders the west side of the county, and in the lower parts of some of the other tributaries of the Kentucky.

PENDLETON COUNTY.

SURFACE FEATURES.

Pendleton County is situated in the northeastern part of the Blue Grass region. Its surface presents many steep-sided valleys separated by narrow, winding divides, the surface of the upland being so uneven that roads ordinarily follow either divides or valleys. Two rock terraces—the upper but little below the level of the upland and the lower less than 50 feet above the level of the stream—extend along the valleys of the rivers. The lower terrace is in but few places more than a mile wide, but the upper terrace is much wider.

Licking River is joined by its South Fork near the center of the county, and these two streams receive the entire drainage, but the tributaries of both are small. The most important of the tributary streams are Kindale, Grassy, Fork, Lick, and Crooked creeks. All of these except Kindale Creek head in Grant County and flow eastward across western Pendleton County. Kindale Creek rises in Bracken County, and flows northwestward to join the Licking north of Falmouth.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soils of Pendleton County consist of thin deposits of heavy clay, which furnish practically no water except where they rest on the dense shales of the Eden formation.

On the lower terrace in the river valleys are deposits of sandy gravel which locally exceed 30 feet in thickness; one record of drilling in the northern part of the county gives the alluvium a thickness of 80 feet, but this is probably too great. The upper terrace bears thin patches of sand and gravel belonging to the Irvine formation. The alluvium supplies an abundance of water for springs along the river banks and should be a satisfactory source of water for wells.

CONSOLIDATED MATERIALS.

The Lexington limestone is exposed in this county along the rivers, where it occupies the bottoms and lower slopes of the valleys. It furnishes an abundance of hard water in the valleys of the Licking and its South Fork. No deep wells have been drilled for water in this formation and none have penetrated the Highbridge limestone; but water obtained in either of these formations at depths greater than 75 to 100 feet, would probably be highly mineralized.

A strip of Winchester limestone is found above the Lexington. This formation, however, occurs not only along the river bottoms, but extends considerable distances up the valleys of the principal tributaries. It furnishes moderate quantities of hard water where it is at the surface, and the formation also supplies some springs of salt-sulphur water in the valleys of the streams. Where the Winchester is buried beneath the Eden shale its water would be too highly mineralized for ordinary uses.

Above the Winchester limestone, forming most of the surface of the county except in the valleys of the large streams, is the Eden shale, which supplies small quantities of water for springs and shallow wells but will yield no water to deep wells.

Narrow belts of limestone belonging to the Maysville formation cap the divides in the western part of the county. These rocks contain some excellent springs and supply considerable water for shallow wells.

Flowing wells may be obtained from the St. Peter sandstone in the valley of Licking River. The well at Boston Station obtains its supply from this formation. The water contains a large amount of salt and is highly charged with hydrogen sulphide. It has proved entirely satisfactory for stock, but is unfit for other uses.

ROBERTSON COUNTY.

SURFACE FEATURES.

Robertson County is near the southeast corner of the Blue Grass region, on the east side of Licking River. Its surface is a deeply dissected plateau, whose steep-sided valleys, 100 to 300 feet deep, are separated by narrow divides with even, sinuous crests. An

abandoned stream channel passes near Kentontown and joins Licking River Valley below Claysville. The rock floor of this valley is in many places covered with 5 to 10 feet of sand containing a few pebbles of chert.

The surface drains toward the west or north into Licking River or its North Fork. The principal stream, Johnson Creek, crosses the county south of Mount Olivet, and there are also many small streams, most of which are less than 10 miles long.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soil of Robertson County is a yellow or reddish clay, which as a rule forms a thin deposit on the uplands. On the slopes it contains many slabs of limestone which have been left as the soil has washed, and in some parts of the county these slabs are so numerous that they furnish enough rock to construct the pikes. The soil yields very little water for either springs or wells.

Some small, unimportant patches of sandy alluvium are found in the valleys of the large streams. The alluvium of the Licking Valley supplies water for some springs, and wells sunk in it would probably be successful. A few wells in the abandoned stream valley near Kentontown procure a plentiful supply of soft water from sand and gravel at depths of 10 to 15 feet.

CONSOLIDATED MATERIALS.

The Lexington limestone outcrops in the valleys of the streams in the western part of the county, but a short distance back from the main streams it is overlain by younger formations, and its eastward dip carries it down to the water level near the eastern boundary of the county. Where it is exposed in the stream valleys wells and springs obtain from it considerable potable water, but elsewhere it will yield only salt and salt-sulphur waters. Such waters might also be encountered in deep wells near the river.

The Winchester limestone appears at the surface in a narrow area near Licking River and its tributaries, where it yields moderate quantities of water for springs and shallow wells. In other parts of the county it is buried beneath younger geologic formations and may be expected to furnish only salt or salt-sulphur water. Some of the deeper wells in the area where the limestone is exposed may also encounter mineral water.

The Eden shale forms the surface rock over a large part of the county, and in most places it furnishes small quantities of water for shallow wells and springs, though the supply is apt to fail in very dry weather. It supplies no water to deep drilled wells.

The lower members of the Maysville formation may cap some of the higher parts of the county, but these members contain a high percentage of shale, and their water capacity is about the same as that of the Eden shale.

The Highbridge limestone will furnish only salt or salt-sulphur water in this county.

Wells sunk on the upland of the county would probably reach the salt-sulphur water of the St. Peter sandstone at a depth of about 900 feet. In the valley of Licking River flowing wells might possibly be obtained from this formation, as the bed of the river was found by aneroid measurement to have an altitude of 580 feet above sea level. As aneroid measurements are subject to considerable error, the determination of altitude is questionable.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

Dug wells, ranging in depth from 10 to 25 feet, supply water for domestic use over a large part of the county, but their use in the towns is attended by some risk, as they are liable to be more or less contaminated by surface drainage.

Drilled wells have been sunk at Mount Olivet and Piqua. At Mount Olivet two wells, 107 feet deep, were drilled, one of which obtained a moderate supply of mineral water and the other was dry. At Piqua a drilled well encountered sulphur water at a depth of about 75 feet.

The springs of Robertson County are all small, and many of them can not be relied upon to furnish water during very dry seasons. The original Lower Blue Lick Spring was located on the north side of Licking River in this county, but this spring ceased to flow some years ago, and attempts to obtain the water by drilling have been unsuccessful. A spring with water of similar character on the other side of the river is now utilized by the company. In the table of analyses (p. 210) the first three samples were taken from the old spring and the fourth and fifth from the one now in use.

SCOTT COUNTY.

SURFACE FEATURES.

Scott County is situated in the south-central part of the Blue Grass region. A gently rolling surface, with variations in altitude of 100 to 200 feet, characterizes the southern part of the county, the interstream areas showing, as a rule, slight relief and being marked by numerous sink holes. In the northern part of the county the surface has been greatly dissected and presents steep-sided valleys separated by narrow divides. The highest points in the county are nearly 1,000 feet above sea level; the lowest are between 600 and 700 feet

above; and the maximum variation is therefore between 300 and 400 feet.

The northern part of the county drains into Eagle Creek and the southern part into Elkhorn Creek. Several tributaries of Licking River head near the eastern boundary and receive the drainage of the eastern part of the county.

The underground drainage of the southern part of the county is extensive, and some of the underground streams may be traced for a distance of 3 or 4 miles by the lines of sink holes that mark their courses. As a rule, an underground stream emerges in a spring at the head of a small branch.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The unconsolidated materials of Scott County form a thin mantle of residual soil, consisting of 3 to 8 feet of brown or red loam on areas underlain by limestone, and 3 feet or less of yellow or red clay where the underlying rock is shale. These materials yield little water except where they rest on a dense rock, like the Eden shale, and even in such places the supply is small.

CONSOLIDATED MATERIALS.

The Lexington limestone is the surface rock over nearly all the southern part of the county, its outcrop coinciding very closely with the area of well-developed underground drainage and rolling topography. The northern boundary of this limestone is a sinuous line extending in an east-west direction across the county about 5 miles north of Georgetown. The formation furnishes an abundance of hard water for springs and wells, and it contains all the large underground streams that supply the important springs of the county. Below drainage levels, however, the water contains salt, and in some places sulphur, and where the limestone is covered by younger formations it will yield no fresh water.

A narrow band of Winchester limestone occurs along the northern border of the area of Lexington limestone, and another extends from the western boundary of the county near Switzer to Greendale in Fayette County. Where this rock is at the surface it furnishes moderate quantities of water for springs and shallow wells, but below drainage levels the water is brackish and is, as a rule, charged with hydrogen sulphide. In localities where it is covered by the Eden shale the water found in it will probably contain both salt and sulphur.

The Eden shale outcrops in the northern part of the county and over a small area in the western part. The rocks of this formation have been deeply eroded and their outcrop coincides very closely with the area of rugged topography. In some places this shale

yields small quantities of water for springs and shallow wells, but it yields no water for deep wells, and the supply obtained by the shallow ones is apt to fail in dry weather.

The Highbridge limestone lies about 200 feet below the surface in the southern part of the county, but it is probably nearly 500 feet below the tops of the highest hills in the northern part. It will yield only brine in this county.

The St. Peter sandstone, with its salt-sulphur water, underlies the entire county, but flowing wells are precluded by the altitude of the surface. In the lowest parts of the county the water should rise to within less than 100 feet of the surface. At Georgetown and Rogers Gap strong salt-sulphur was reported in two deep wells at depths of 700 and 900 feet, respectively. At Georgetown this water was said to have sufficient head to rise within 15 feet of the surface. If this is the water from the St. Peter sandstone, it was encountered at a less depth and rose higher than the water from the same formation at Frankfort.

STRUCTURAL FEATURES.

The rocks of Scott County have a general dip toward the north, and there are some evidences of slight local disturbances. The most marked structural features are found southwest of Stamping Ground, where two nearly parallel faults have brought a block of Eden shale into contact with the Lexington limestone. Near Georgetown a slight deformation has produced a small fold.

WATER FOR DOMESTIC AND INDUSTRIAL PURPOSES.

Dug wells are used to a limited extent in Scott County, but they are rapidly being supplanted by drilled wells except in the areas underlain by the Eden shale. Most of the drilled wells obtain their waters from the Lexington and Winchester limestones at depths of 50 to 125 feet. The depth to the sulphur water in Scott County varies locally, but it is in few places more than 100 feet.

The Georgetown water supply, which is taken from a large spring on the edge of the city, is the only large underground supply of the region. The fact that this water is usually turbid after a rain suggests that some water enters the underground stream through open sinks. The spring is supplied by a good-sized underground stream, and the amount of water is usually much greater than is needed by the town. Many other large springs are found in various parts of the county.

Sadieville and Stamping Ground have drilled wells belonging to the towns, and these wells supply water for the families that do not use cistern water. At Newtown the underground water conditions appear to be very favorable, and a large number of successful wells have been drilled.

SHELBY COUNTY.

SURFACE FEATURES.

Shelby County is on the western edge of the Blue Grass region. Except near its eastern boundary, where some of the streams have cut narrow valleys 200 to 300 feet below the level of the upland, it has a gently rolling surface, with variations in altitude exceeding 100 feet in but few places. Near the northwestern corner of the county is a high ridge which forms the divide east of Floyds Fork, and a high hill, known as the "Jeptha Knob," is situated near the village of Claysville.

A small area near the eastern margin of the county drains to Kentucky River through Sixmile and Benson creeks, whose principal tributaries are Backbone Creek (to Sixmile) and Collets Creek (to Benson). The rest of the county is drained by tributaries of the North Fork of Salt River, the largest being Big Beech, Guests, and Brashears creeks, and Floyds Fork. The southeastern corner of the county, south of Harrisonville and Southville, is drained by the Middle Fork of Crooked Creek and Big Beech Creek and its tributaries; a large area east of Shelbyville and south of Christiansburg is drained by Guests Creek and its tributaries, Jeptha and Lick creeks and Breton Run; and the central part of the county is drained by Brashears Creek, to which Clear and Big Bullskin creeks are tributary. Floyds Fork of Salt River receives no large streams from Shelby County, but the drainage of the northern part of the county reaches it through several small streams. Plum Creek, a direct tributary of Salt River, drains the southeastern corner of the county.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual soils of Shelby County resemble those of Fayette County, including dense red or yellow clays on the areas of Eden shale and loams rather than clays on the limestones of the Maysville and Richmond formations. The residual soils from the Eden shale furnish small quantities of water during wet weather. In a few localities the soils on the Maysville formation contain so much water that tile draining is necessary, and in such places they should furnish some water for wells.

CONSOLIDATED MATERIALS.

The Highbridge, Lexington, and Winchester limestones underlie the entire county, and the Lexington and Winchester are exposed near Graefenburg in the valley of Benson Creek. The Winchester limestone appears also in the channels of several other streams near the eastern edge of the county. Where these limestones are at the surface sufficient hard water for a farm is usually obtainable, but in some

places they yield salt-sulphur water like that of the mineral spring at Graefenburg. These formations might be reached by deep wells sunk on the upland, but the water of such wells would probably be saline or saline-sulphur in character.

The Eden shale forms the surface rock over a belt 2 to 6 miles wide along the eastern boundary of the county, and outcrops also in the valley of Brashears Creek and in the valleys of Guests Creek and its principal tributaries. In the eastern part of the county this formation supplies small quantities of water for springs and shallow wells, but farther west it is covered by younger rocks and is not water bearing.

Rocks belonging to the Maysville and Richmond formations occupy nearly all of the surface west of the exposures of Eden shale and furnish moderate quantities of hard water for springs and shallow wells. The underground water conditions appear to be most favorable in the western half of the county, but perennial springs occur in all parts of the area where these formations are at the surface.

The Panola formation caps the ridge east of Floyds Fork in the nothwestern part of the county. On Jeptha Knob, and near the northwest corner of the county, it furnishes ample supplies of hard water for farm use. A cavern containing a stream of water is reported on Jeptha Knob.

The St. Peter sandstone will supply an abundance of water for deep wells in this county, but it is improbable that the water will flow at the surface. The quality of this water is shown by the analysis of the water from the Old 76 distillery at Newport (p. 212). The water is too highly mineralized for domestic or industrial uses.

STRUCTURAL FEATURES.

The rocks of Shelby County dip gently toward the northwest. They show no marked dislocations except near Jeptha Knob, where they are broken by faults which have brought limestones of Niagaran age into contact with some of the older rocks of the Maysville formation.

WATER FOR DOMESTIC AND INDUSTRIAL USES.

In the western part of this county some drilled wells, 50 to 100 feet deep, have obtained good supplies, but over a large part of the county drilled wells may yield very little water. A conspicuous example of a failure to find water is the well on Mr. Goodloe's farm, northeast of Shelbyville, which was carried to a depth of about 750 feet. Another well a short distance away obtained a good supply at less than 70 feet. In this county drilling should not, as a rule, be carried beyond 100 feet, and 150 feet should be the maximum depth unless mineral water is desired.

None of the formations exposed in Shelby County will supply sufficient water for a city system except the Lexington limestone, and

even this formation may be expected to yield large supplies in only a few localities where conditions are especially favorable.

In Shelbyville, which is situated on rocks of the Maysville formation, it is practically certain that underground water of suitable quality and sufficient in quantity for a city supply is unobtainable, and the only alternative is the use of surface water. Filtered surface water, however, would compare very favorably with the underground water of the region.

TRIMBLE COUNTY.

SURFACE FEATURES.

Trimble County is in the western part of the Blue Grass region and is bordered by Ohio River. The eastern part of the county has a gently rolling surface with broad shallow valleys separated by rounded divides, except near Little Kentucky River, which has cut a narrow trench 200 to 300 feet below the level of the upland. West of Bedford the streams flow in deep, narrow valleys which are separated by broad, flat, interstream spaces. The amount of relief increases toward Ohio River, where it approximates 400 feet.

The Little Kentucky, which crosses the eastern part of the county, receives the drainage of the area east of Bedford. The area west of Bedford is drained by several small tributaries of the Ohio, the most important being Pattons, Barebone, Corn, Spring, and Cooper creeks. None of these streams exceed 10 miles in length and all of them have very high gradients.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The unconsolidated materials of Trimble County include a mantle of glacial deposits in the western part of the county and of residual soils in the eastern part, with a deposit of alluvium 80 to 120 feet or more in thickness in the Ohio Valley.

The eastern boundary of the glacial deposits extends northward from the Oldham County line, passing about 5 miles east of Bedford and entering Carroll County west of Little Kentucky River. The material of these deposits is a red clay containing many fragments of chert and some pebbles of limestone. A few small fragments of igneous rocks occur in the till, but most of the pebbles are of local origin.

The residual soils of the eastern part of the county consist of dense clays, in few places more than 3 feet thick, which furnish little water directly to wells or springs except where they rest on the Eden shale.

The alluvium of the Ohio Valley consists of coarse sands and gravels capped in many places by a few feet of buff silt. These materials supply an abundance of hard water for drilled or driven wells at depths of 60 to 110 feet. The water is not so hard as that derived from the consolidated materials on the upland.

CONSOLIDATED MATERIALS.

The oldest rock appearing at the surface in Trimble County is the Eden shale, which is exposed at the foot of the bluff bordering the Ohio and in the valleys of Little Kentucky River and some of the smaller streams in the northeastern part of the county. In these valleys it furnishes small quantities of water for springs and shallow wells, but elsewhere in the county it is buried by younger formations and is not water bearing. The quality of much of the water from this shale is poor.

The eastern half of the county is underlain by rocks belonging to the Maysville and Richmond formations, which furnish moderate quantities of hard water for springs and shallow wells. The Richmond is especially well developed, more than 150 feet of interbedded limestones and shales belonging to this formation being exposed near Bedford. The upper part of the Richmond presents exceptionally favorable conditions for underground water and contains some very good springs. In some drilled wells the water is slightly brackish.

A large part of the upland near the Ohio is occupied by the blue shale and gray to buff heavy-bedded limestones belonging to the Panola formation. The limestone beds of this formation yield ample supplies of water containing considerable lime and magnesia. Some of the layers that rest on shale beds present unusually favorable conditions for underground water. Northwest of Bedford some large sink holes suggest the presence of good-sized caverns.

The Winchester, Lexington, and Highbridge limestones and the St. Peter sandstone are all buried beneath younger rocks in this county and will not yield fresh water, but any of them may yield salt-sulphur water in deep drilled wells. In the Ohio Valley flowing wells could be obtained by drilling into the St. Peter, but the quality of the water in this formation renders it unfit for ordinary uses.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

A number of good springs are found in the western part of Trimble County, but from Bedford eastward the springs are small and many of them fail during dry seasons. The Bedford mineral spring was formerly a summer resort of considerable note.

Dug wells from 10 to 30 feet deep are a common source of supply for farms and villages. During recent years many of these wells have been supplanted by cisterns.

Drilled wells are usually successful on the upland west of Bedford, but few of them procure large supplies. At Bedford two unsuccessful wells have been drilled.

WOODFORD COUNTY.

SURFACE FEATURES.

Woodford County lies in the southern part of the Blue Grass region, on the east side of Kentucky River, which is here less than 500 feet above sea level; the highest parts of the upland have an altitude of nearly 1,000 feet.

The drainage of the county reaches the Kentucky through Clear, Glen, and South Elkhorn creeks and many small streams. All the surface streams receive large quantities of water from springs fed by underground streams. Such underground streams occur in all parts of the county, but they appear to be especially large and numerous on the divide northeast of Versailles. On this divide are many sink holes which receive the drainage from considerable areas. An example of this is the big sink northeast of Versailles, which receives the drainage from a surface stream more than a mile in length and which is said to be connected by an underground channel with the Big Spring. This spring, which is probably the largest in the Blue Grass region, emerges from a cavern, flows for some distance as a surface stream, and then enters an underground channel through a sink hole. Other examples of sinking streams are to be found on the Woodburn farm, near Spring Station, and at Childer's place, near Versailles. In this county, as elsewhere in the region, most of the large springs emerge in small gullies. Caverns of considerable size exist in various parts of the county, and some of them have been explored for short distances.

Most of the surface streams tributary to the Kentucky have broad valleys on the upland and descend to the river in narrow canyons.

GEOLOGY AND UNDERGROUND WATERS.

UNCONSOLIDATED MATERIALS.

The residual materials in Woodford County consist of yellowish or reddish loams and clays which were formed by the decomposition of limestones and shales and which probably have an average thickness of less than 6 feet, although in some places the maximum thickness may exceed 20 feet. These materials furnish little water directly to wells or springs, but they store large quantities of water and supply it gradually to the channels in the limestone.

Thin strips of sandy alluvium, which supplies large quantities of water to springs on the banks of the river and might also furnish an abundance of water for wells, are found in the wider parts of the gorge of Kentucky River. The thickness of this alluvium has not been determined by borings, but it probably does not exceed 50 to 60 feet.

CONSOLIDATED MATERIALS.

The Highbridge limestone is exposed in the gorge of Kentucky River, but it dips steeply northward and the thickness of the exposure decreases toward the northern end of the county. Where it forms the surface rock it furnishes hard water for springs and shallow wells, but elsewhere it yields water which is highly mineralized.

The Lexington limestone is exposed above the Highbridge along the valleys of the large streams and it forms the surface rock over a large portion of the upland. It is this limestone that contains the large underground streams referred to in a previous paragraph. In the localities of its outcrop it furnishes an abundance of hard water, but wells which penetrate it below the level of the surface drainage are apt to obtain salt or salt-sulphur water.

The Winchester limestone outcrops over considerable areas in the northern half of the county and supplies moderate quantities of hard water. It may also supply some of the sulphur water which is encountered in the drilled wells of the northern part of the county.

The Eden shale, which caps some of the hills in the northwestern part of the county, furnishes small quantities of water to springs and shallow dug wells, but none for deep wells.

The St. Peter sandstone will supply salt-sulphur water at depths ranging from 700 to 800 feet in the gorge of Kentucky River to 1,200 feet or 1,300 feet on the upland. The water is under sufficient pressure to cause it to flow at the surface in the Kentucky gorge and in the lower parts of some of the tributary streams.

DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

Dug wells are used to a moderate extent in Woodford County, but they are not held in great favor. Drilled wells are numerous in all parts of the county, and the water conditions are so favorable that many drillers agree to obtain water or make no charge for drilling. At Versailles about 100 wells have been drilled and none of them have failed to get water, while some have yielded over 100 gallons per minute.

The large spring at Spring Station probably has a greater volume than any other spring in the Blue Grass region. The flow of this spring was not determined, but it must amount to several million gallons per day.

WELLS AND WELL RECORDS.

The following list of well records (Table 8) includes about 75 per cent of the number that was collected during the progress of the field work. No attempt has been made to obtain records of all the wells in the region, but the list is believed to represent the underground water conditions and to indicate what may be expected by those who contemplate drilling.

The wells in the alluvium are all located in the Ohio Valley. Wells sunk in this formation always procure water, unless they are located so close to the upland that they encounter rock near the surface. The water is entirely satisfactory for ordinary use and the supply ample.

The wells on the upland have been sunk in various formations, but it will be noted that none of the deep wells obtain water from the Eden shale. In the other formations the water supply varies in amount and character in different localities. Large supplies are encountered in many places in the Lexington limestone, while few wells in the Maysville and Richmond formations obtain more water than is needed for a single household. In the Winchester limestone underground water conditions are somewhat less favorable than in the Lexington. The Panola formation is seldom thick enough to warrant deep drilling, but near the western edge of Oldham and Trimble counties it supplies a number of good drilled wells.

In all of these formations, except the Panola, the deeper wells are apt to encounter the highly mineralized water which is designated sulphur water in the table. The depth to this mineral water varies from place to place and in different wells in the same locality; but in general the table will form a safe guide to the approximate depth of the ordinary limestone water, beyond which mineralized waters are probable.

In consulting the table it is well to remember that a well in any locality may fail to obtain water. In the Blue Grass region the number of unsuccessful wells is about 4 per cent of the whole number drilled. For the region as a whole, therefore, the probability of success in seeking water is very good, but the percentage of dry holes is much higher in some localities than in others. It may happen that some wells find water while others a few feet away are dry. This is explained by the fact that the water occurs in channels in the rock, and to be successful a well must encounter one of the water-bearing channels. The accompanying diagram, figure 5, shows two wells side by side—one successful, the other dry.

About 100 records were collected by Dr. Chase Palmer and the remainder by the author. Much valuable information in regard to the occurrence of underground water in the region was also furnished by the drillers whose names are given below:

J. B. Bonta.
E. C. Cox.
W. M. Cox.
E. C. Griggs.
George Icenhower.
John Kearney.
W. S. May.
Patton & Bailey.
W. R. Renfro.
Robinson & Moon.
George Sallee.
S. Wells.
Robert Smith.
E. M. Spence.
John O. Rogers.
W. B. Tadlock.

TABLE 8.—*Wells in the Blue Grass region.*

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (—) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Anderson County.														
Lawrenceburg	2 blocks W	City	*In.* 8	*Feet.* 75-100 240	*Feet.* 40-45	*Feet.* Small streams	*Feet.*	*Galls.*		Hard; trace sulphur.		Lexington	Domestic, stock, boilers, manufacturing.	3 wells.
Do	200 yards NW	do	12-4	125	125	50	—110	150	Steam	Sulphur	Lowered	do	Domestic, stock.	
Do	150 yards W	do	8	245	45	None.	— 8	60	Deep well	Hard	do	do	do	
Do	5 miles N	Kentucky Distillery and Warehouse Co.; Blakemore Distillery.	6	50	48		— 5	100	Steam	Hard; sulphur.	None	do	Boilers, manufacturing.	
Do	½ mile S	Lawrenceburg Electric Light Co.	6	135			— 10	15	do	Hard		do	Manufacturing.	
Do	2 miles NW	W. B. Saffell	6	105	30		— 4		do	Sulphur		do	Drinking, manufacturing.	
McBrayer	4½ miles S	J. T. S. Brown & Sons.	8	65	60	None.	— 14		do			do	Stock, manufacturing.	
Do	½ mile SW	do	3,6	70	70	None.	— ½		do		None	do	Domestic, manufacturing, stock.	
Tyrone		City	6	80					Hand	Hard, and one white sulphur.	do	Highbridge	Domestic, stock.	11 wells.

Boone County.														
Bellevue	1 or 2 blocks	Bellevue		130	120–130	Above 120.			Hand	Hard	do	Alluvium	Stock	
Petersburg	3 blocks W	Boone County Distilling Co.		110	90–100	Small, above 90.			Steam	do	do	do	Manufacturing.	
Do	1 block E	F. M. Morgan	2	80	40				do	do		do	Boilers	
Do	1½ miles S	Frank D. Smith		100	80				Windmill	do		do	Drinking, stock.	
Do	1 block S	Town	4	115	100	None.			Hand	do	Varies, but plenty.	do	Domestic, stock.	
Do	½ mile N	J. I. McWorthey	3	132	95	None.			Windmill	do	None	do	Stock	
Rabbit Hash	1 mile S	John McConnell	4	95	60	None.	− 60	4	do	do	do	do	do	
Taylorsport	½ mile E	P. Grubbs	3	110	32		− 18			Sulphur	do	do	do	
Bourbon County.														
Centerville	1 mile W	J. B. Haggin	5½	125	85		− 50	50?	Gasoline engine.	Hard; sulphur		Lexington	Stock	
Clintonville	1 mile N	S. L. Weathers	8–6	50	45	25		30	Meyer's hand.	Sulphur	None	do	Domestic, stock.	
Elizabeth Station.	1 block N	John M. Leach	6	55	50	None.		4	Hand	Hard, some sulphur.	Lowers.	do	Stock	
Hutchison	100 yards W	M. R. Jacoby	6	72	72	None.	− 52		Windmill	Sulphur	None	do	Domestic	
Do	3 miles W	do	6	68	68	None.	− 15	8	Hand	Hard	do	do	do	
Millersburg		Millersburg Female College.	6	60	None.									
Do		do	6	120	None.									
North Middletown.	2 miles N	William Thomason.		40	40				Gasoline engine.	Slight sulphur		do	Domestic, stock.	
Paris	1 mile S	Bourbon County Fair Association.	6	113	103	67	− 52		Hand	Hard; some sulphur.		do	Drinking	
Do	5 blocks W	Bourbon Steam Laundry.	8	90+			− 25		Hand, force.	Hard; slight sulphur.		do	Domestic, stock, manufacturing.	
Do	1 mile NE	Paris Distilling Co.	6	120			30			Hard; strong sulphur.		do		Not used.
Do	7 miles SE	Benj. Woodford		168		None.	− 40		Hand			do		
Do	5 miles S	W. B. Woodford	6	50	40	None.	− 20		Suction	Soft		do	Drinking	
Boyle County.														
Danville	2½ miles NW	Charles P. Cecil	5	90	85		− 35		Windmill	Sulphur		do	Domestic, stock.	
Do	2 miles	W. W. Johnson	4	180	90	None.		½	do	Hard	Lowered	Lexington	Washing, stock.	

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks
Boyle County—Continued.														
			In.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Danville	3 miles E	D. F. Slavin	4	125	125	None.	− 50		Windmill	Hard	None	Lexington	Domestic, stock.	
Enido	¼ mile W	J. L. Crain	6–4	65	62	38	− 45	1	Force	Soft; sulphur			do	
Hankla	¾ mile W	George Gordon	6	51	51		− 27			Sulphur	None		do	
Do	1½ miles W	W. F. Powers	6	58			− 32				do		do	
Mitchellsburg	200 yards E	School district	6	72	72	40±			Hand	Hard; sulphur	do	Chattanooga.	Drinking.	
Do	East	L. R. Wharton	6	73	73		− 33		do	Sulphur	do	do (?)	Domestic, stock.	
Parksville	50 yards W	Lapp Ewing	6	100			− 8						Domestic, stock, boilers.	
Do	200 yards NE	J. D. Minor	6	57			− 30				Weak supply.		Domestic, stock.	
Perryville	4 blocks E	Samuel Bonta	4	60	60	None.	− 40		Force	Soft; black sulphur.		Lexington	do	
Do	1½ miles SW	J. W. Broghs	4	56		None.	− 25		Hand	Slight sulphur.	None	do		
Do	250 yards W	J. A. Carpenter	6	67	67	None.	− 45		Force	Sulphur		do	Domestic, stock.	
Do	2½ miles N	J. W. Moss	6	100	100				Windmill	Hard; possibly oil.		do	Stock	
Do	2½ miles E	R. A. Walker	6	125	125	None.	− 93		Deep well	Hard; salt, oil, and iron.		do	Cooking, stock.	
Do	300 yards W	George Warren	6	82	82	None.			Force	Slight sulphur.		do	Domestic, stock.	
Do	3 miles W	Richard G. White.	6	70	70	None.	− 40			Slight sulphur and gas.		do	Domestic.	
Bracken County.														
Augusta	1 block S	Augusta Milling Co.	4	85	40		− 40	45	Steam	Hard	None	Alluvium	Boilers	

Do	3 blocks E	Augusta Steam Laundry.	2	80	60			25+	do	do	Not lowered when 25 gallons were pumped.	do	do	
Do	2 squares W	J. R. Carter	6	86	80	50	−40	Unlimited.	Hand	do		do	Drinking, stock.	
Do		City	3	90-115	40-50	10, 40-50	−50±		do	do		do	Domestic, stock, boilers.	
Do	2 blocks NW	do	6	96	50±		−46	60+	Steam	do	None	do	Boilers	
Do	1½ miles W	E. F. Frolicher	6	170	170	None.	−60+		Hand; gasoline engine.	Mineral		Winchester (?)	Drinking	
Foster	1 block N	Town	6	106	102	30	−70±		Hand	Hard	Slight	Lexington	Domestic, stock.	Abandoned.
Wellsburg	15 rods	Noble Stair		68	35				Steam	do		Alluvium	Drinking, washing, boilers.	
Campbell County.														
Newport	4 miles S	Bastian dairy	4	101	−65	Several veins.	−40	15	Hand	do	None		Stock	
Do	Evergreen Cemetery.	Evergreen Cemetery Co.	4	600	200	None.	−194	1⅔	do	Slight sulphur.	do	Maysville and Eden.		Probably entered Trenton.
Do	Berry ave between 2d and 3d.	Frigid Ice Co	10	122	52	122	−52	209	Steam	Hard	do	Alluvium	Manufacturing.	Uses water for cooling.
Do		Old 76 Distilling Co.	3	1250		A little fresh water.		34+		Sulphur	do	St. Peter	Drinking, manufacturing.	Very strong salt-sulphur.
Do		George Weidemann Brewing Co.	10	110, 275	80	None.	−70	350	Air lift	Hard	do	Alluvium	Manufacturing.	Uses several wells for cooling purposes.
Carroll County.														
Carrollton	½ mile W	Atkinson Bros. Co.	3	70	45		40			do		do	Boilers	
Do	½ mile S	Carrollton Furniture Manufacturing Co.	3	98					Steam	do	None	do	Drinking	
Do	5 miles NE	G. H. Conway	8-6	540	20	540	−90							
Do	½ mile S	Jett Bros. Distillery Co.	5,8	80-90	40		−40	300	Steam	Hard		Alluvium	Boilers, manufacturing.	Six wells.

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply	Geologic horizon of water beds.	Use.	Remarks.
Carroll Co.—Cont'd.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Ghent		City of Ghent	4	108,94	70		− 80	2	Hand	Hard	None	Alluvium	Domestic, stock.	
Do	1½ miles NE	H. M. Froman	2	114	85	114	− 35	1	Windmill	do	do	do	do	
Do	1½ miles N	do		150					do			do	Stock	
Milton	4 miles E	C. S. Tandy	3	82	60		− 60		Hand	Hard		do	do	
Sanders	4 miles NE	F. B. McDonald	8¼	841	840					Hard; sulphur		Lexington		
Clark County.														
Dodge	Across road S.	S. D. Chism	6	58	54	None.	− 38		Hand	Sulphur	None	Winchester	Domestic, stock.	
Do	40 rods W	G. T. Roland	6	50	44	None.	− 15		do	Sulphur; salt	do	do	Drinking, stock.	
Hedges	1½ miles SE	L. T. Bush	5	113	75–80	None.	− 70		do	Salt; sulphur	do	Lexington	Domestic.	
Pine Grove	1½ miles S	A. Younger Jones.	4½	90	80–85	50–55	− 65		Gasoline engine.	Hard	do	do	Domestic, stock.	
Do	100 yards NE	D. W. Scott	4½	134	127	None.	− 96+		Hand	Hard; magnesia.	Slight	do	do	
Winchester	5½ miles N	Oscar Johnson	5	70–75					Windmill.	Strong sulphur	None	Winchester	Stock	
Do	½ mile E	Reliance Manufacturing Co.	4½	55+	35	42				Sulphur		do		
Do	½ mile S. of E.	R. P. Scrobble	6	100										No water of importance
Do	¼ mile N	Winchester Electric Light and Ice Plant.	6	132,112								Lexington		Salt water, unfit for use.
Do	6 miles N	N. H. Witherspoon.	5	146	140				Hand	Sulphur	None	do	Drinking.	
Wyandott	2 miles	B. M. Renick	4	145,165	100	None.			Force		do		Domestic, stock.	
Fayette County.														
Chilesburg	2 miles N	Rev. W. H. Felix		75		do			Gasoline engine.	Salt, iron, and sulphur bearing.		Lexington	Drinking, stock.	

Elizabeth	1½ miles S	Abram Jones	6-4	150	150	60	— 50		Force	Soft		do	Domestic, stock.	
Greendale	½ mile W	Kentucky Reform school.	5	214,212					Steam			Highbridge	Domestic, stock, boilers.	
Do	½ mile E	S. C. Nunnelly		230		Above 30.			Hand	Sulphur	Strong supply.	Lexington (?).		Not used now.
Do	1 mile NW	State	5	214,212	60,75	101,175	— 75 to — 60	35	Steam and gas.	do		Highbridge (?)	Domestic, manufacturing.	
Lexington	5½ miles Georgetown Pike.	Dr. Aiken	4	200	94	40			Windmill.	Hard	None	Lexington	Stock	
Do	¾ mile NW	Blue Grass Stock Yards.	6	84,124			— 40+		Horse-power.	do	do	do	do	
Do	1½ miles NE	Boice & Grogan Lumber Co.	8	116	50	20		40	Deep well	do	Varies	do	Boilers	
Do		City Ice Co	6	190					Steam			do		Not used.
Do	1½ miles N	Benj. M. Cole	4½	95	95	None.			Force	Alkaline	None	do	Domestic, stock.	Mineral water.
Do	¾ mile W	Consumers' Ice Co.	8, 5, 5	400, 150, 100	274			100		Sulphur		do	Manufacturing.	450-foot well enters Highbridge limestone.
Do	10 miles N	B. S. Coyle	4¼	100	80	None.	— 35	3	Force	Hard	Lowered	do	Drinking, stock.	
Do	do	do	4¼	112	110	70	—100	60	do	Limestone	None	do	Domestic, stock.	
Do	10 miles	do	4¼	142	80-130	None.	— 30	7	do	do	do	do	do	
Do	5 miles SE	R. C. Estill	5-4	225	150	25,65	— 45		Hand	Salt; sulphur.		Highbridge (?)	Stock	
Do	5½ miles SW	Alex. Foley	6	71	71				do	Hard	None	Lexington		Not used.
Do	1½ miles W	G. R. Foster	4½	200	90		+ 0			do	Varies	do	Drinking, manufacturing.	
Do	3 miles N	John N. Foster	4¼	100	—5, —65			66	Steam	do		do	Irrigation.	
Do	¾ mile SW	Gentry heirs	4	85					Windmill, electric motor.	do	None	do	Stock	
Do	12 miles E of S.	Dr. D. J. Gibson.	5	52	40	None.	— 27		Hand	Slight sulphur	do	do	Domestic, stock.	
Do	10 miles NE	J. B. Haggin		165					Windmill.	Sulphur	do	do	Stock	Has several other wells
Do	7½ miles S	do	6	198			— 90		do	Salt: sulphur		do		Very highly mineralized.

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface of well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Fayette Co. Cont'd.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Lexington	1½ miles W	J. R. Hughes	6	85				6+	Gasoline engine, windmill.	Hard	None	Lexington	Stock	
Do	5 miles NW	Ed. Kane	4	78			−40		Hand			do	Domestic, stock.	
Do		Lexington Brewery Co.	5	143	142	30, 80			Steam	Hard		do	Manufacturing.	
Do		do	8	150	142	30, 80	−8 to 15	230	do	do		do	do	
Do	1½ miles E	Lexington Brick Co.	4	180	12	None.	8 to 30+		do	do	Varies	do	Drinking, manufacturing.	
Do	1½ miles NE	L. and E. R. R.	8	187	45 or 50	None.	−21	6+	Deep well	do	do	do	Stock, boilers.	
Do	1 block W	Lexington Laundry.	8	175	170	14, 75	−12½	80	Steam	do	None noted.	do	Laundry	
Do	4 miles SE	J. E. Madden	5	60	30			9+	Gasoline engine.	Slight sulphur.	Strong stream.	do	Domestic, stock.	
Do	do	do	5	90				9+	do	Considerable sulphur.		do	do	
Do	do	do	5	125				6+	Windmill	Strong sulphur		do	do	
Do	1½ miles NW	Meadowthorpe Stock Farm.	6	105	95	None.			do	Sulphur	None	do	do	
Do	8 miles S	Z. T. Newman	4	95	70		−65		Hand	Little sulphur.	do	do	do	
Do	12 miles SW	James E. Pepper Distilling Co.	6	50 100 100 130	90	15-16, 49	−7	173	Air lift			do	Distillery	
Do	1 mile SE	William Pettit	4	51	51	None.	−11		Hand		Strong flow.	do	Domestic, stock.	
Do	1¼ miles S	do		65			−10		do	Hard		do	do	
Do		W. R. Renfro	4¼	66	60		−40	5	do	White sulphur and lithia.	None	do	Drinking	Mineral water.

Do	1½ miles N	Alfred Ruh	5½	140	140	62	−60		Force, gasoline engine.	Sulphur	do	do	Domestic, stock, irrigation.	
Do	2 miles SW	Mrs. J. W. Sayre.	4	168	168	48	−70		Windmill.			do	Drinking, stock.	
Do	1 mile SW	Albert Shuler	6	85	83	None.			do	Hard; sulphur.	None	do	Domestic, stock.	
Do	2 miles NW	Dr. J. W. Wilson.	4–4	126	126	None.	−76		Hand	Sulphur		do	do	
Nicholasville	7 miles E	Baptist Church	4	80	78				do	do	None	do	do	
Do	8 miles S	County farm	4	120				4+	do	do		do	Drinking	
Do	7 miles NE	East Hickman Church.	6	150	125	90	−40		do	do		do	Domestic, stock.	
Do	7½ miles SE	Mrs. Keith	4	100+					do	Hard		do	do	
Do	7 miles SE	E. E. Price	4	110	100					Gas		do		Not used.
Do	8 miles SE	Mrs. J. W. Strode	4	100+					Hand	Hard		do	Drinking, stock.	
Walnut Hall		Spring										do		Spring supplies farm.
Fleming County.														
Flemingsburg	1 mile SE	William H. Belt.	6	100			−80		Hand	Hard		Maysville	Drinking, stock.	
Do	¼ mile E	City	6	70								do		Little oil at 65 feet.
Do	½ block N	do	6	125	69	69–73	−30	6	Hand	Hard; slight sulphur.		do	Domestic, stock.	
Do	½ block S	A. H. Evans	6	75	25		−18	20		do	None	do	Drinking, stock.	
Do	⅛ mile E	Henderson & O'Bannon.	6	80	57	None.	−36	15–18	Hand and steam.	Salt, alkaline, iron, sulphur.	Lowers	do	Domestic, manufacturing.	
Do	do	do	6	102	45	Several.	−14	18–20	Steam	do	None	do	Drinking, manufacturing.	Used in ice plant.
Do	2 miles SW	W. J. Hendrix	6	72+	30	18	−40		Hand	Hard	do	do	Domestic.	
Hillsboro	3 miles E	J. W. Gilmore	6	65	60	25	−15		do	do		Panola	Domestic, stock.	Supply easily exhausted.
Do	1 block W	J. H. Shepard	6	140	20					Oil at 100 feet.				Never used, on account of oil.
Muses Mills	2 miles W	W. H. Means	6	1,000	18–20	None.								Very little water.
Poplar Plains	1 mile N	R. F. Deering	6	100+	95					Oil and gas		Maysville(?)	Cooking	Now closed.
Do	400 yards E	E. P. Maggard	6	100	70	10			Hand			Maysville	Stock	Used but little.
Do	do	do	6	120	60	10			do			do	do	Do.
Do		J. W. Patrick	6	100	90+	30,25	−15		do	Hard	Slight	do	Domestic.	

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Fleming Co.—Cont'd.														
			In.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Poplar Plains		Town	6	100								Slight		
Sunset	½ mile W	O. B. Graham	6	71½	35		−3 to −5					do	Stock	Flow caused by gas; stopped in 1 week.
Do	do	do	6	150	120		−3 to −5				Fluctuates	do		
Do	do	do	6	196	40		−3 to −5			Salt; some sulphur.		do	Stock, cooking.	
Tilton (?)		Town	6	80	60	None.	− 1½		(?)	Hard; little salt.	Easily drawn dry.			Well never used
Franklin County.														
Forks of Elkhorn	200 yards N	Albert Hockensmith.	5	70	60+	Small seeps.			Hand	Only strong sulphur when well pumped out.	Empties in 2 hours, but fills in 24.	Lexington	Domestic, stock.	
Frankfort	¾ mile SE	W. A. Gaines & Co.	6–10	70	52	None.	− 30	400	Deep well.	Hard		Highbridge	Manufacturing.	
Do	2 miles W	S. C. Herbst	8–6	300	None.	None.		None.						No water.
Do	4 miles SE	S. French Hogue	5	80						Hard		Lexington	Stock	
Do	1 mile N	James A. Murray	6	1,300	900	None.	+ 80			Sulphur		St. Peter	Domestic, stock.	
Do	3½ N	E. B. Weitzel		90						Hard		Lexington	Stock	
Do	4 blocks E	do	6	200	100	150 (?)	− 40					Highbridge		Supply too small for use.
Grafenburg	½ mile E	Elias Herndon	6	50	45				Hand	Hard	Varies		Drinking, cooking.	
Jett	½ mile W	T. K. Jett	6	65	65		− 45		Windmill.	Very strong sulphur.	None	Lexington	Domestic, stock.	Can not pump dry.
Do	do	do	5½	72	72		− 58		do	do		do	do	Not used.
Do	½ mile S	W. B. Jones	6	50	16+	None.	− 5	All necessary.	Hand	Rather soft		do	Domestic, stock.	

Do.	300 yards N.	L. A. Owen		85					Hard	Pumped dry in 15 minutes.	do.		Do.
Do.	50 feet W.	Lee A. Owen	5	107	107	50+	— 50		Windmill.	Strong sulphur at first, none now.		do.	Domestic.
Do.	150 feet E.	W. B. Quin	6-5	54	30	52	— 20		Hand	Hard	Lowered some.	do.	Domestic, stock.
Do.	1 block NE.	J. R. Shaw	4½	54	50	None.	— 14		Gasoline engine.	Trace of sulphur at first, slight now.	None	do.	Domestic, stock.
Do.	½ mile S.	do.	6	60	55		— 40		Windmill.	Hard		do.	Domestic, stock.
Gallatin County.													
Brashear	1½ miles S.	J. S. Peyton	2	100	100	65	— 20		Windmill.	Soft (?)		do.	
Gex	1 block S.	Thomas Mylor	3	96	50				Hand	Hard	Alluvium	do.	
Ghent	2 blocks NW.	Parker & Deane	2	80					Steam	do.	None	do.	Stock.
Sanders	4 miles W.	G. Cox	8¼	352						Salt water and gas.			
Do.	do.	Mrs. William Roswell.	8½	550	15					Hard			
Do.	250 yards S.	Sanders Oil and Gas Co.	8	741	741		+ 75	−1		Sulphur; salt.			
Warsaw	¾ mile E.	Arch Bell		125	100±		−100	5	Hand	Hard	None	Alluvium	Domestic, stock.
Do.	1 mile S.	Samuel Bledsoe		90±					Windmill.	do.		do.	Stock.
Do.	2 blocks W.	City of Warsaw	2,3	60	50		— 50	8	Hand	do.	None	do.	Domestic, stock.
Do.	Within 3 or 4 blocks.	do.	3	90-100	85±		−85 to −90	8	do.	do.	do.	do.	do.
Do.	3 miles S.	Ashton Craig		103	45			−45	do.	do.		do.	Stock.
Do.	6 miles S.	G. A. Ghex	3	90+	60		— 60		Windmill.	do.		do.	do.	Unlimited supply.
Do.	2 blocks N.	Warsaw Furniture Co.	4	90	80		— 30±	30	Steam	do.	None	do.	Boilers.	Hardness low.
Garrard County.													
Bryantsville	¼ mile S.	C. M. Jenkins	4	60	45	18	— 4	2	Windmill.	do.		Lexington	Stock.	
Hyattsville	1 mile E.	James N. Denny	4	104	104			Small seep.				Maysville		Not used.
Marcellus	3 miles W.	I. M. Dunn	4	54	40	None.	— 40	5	Windmill.	White sulphur		Lexington	Domestic, stock.	
Do.	½ mile E.	A. B. Montgomery.	6	60	35		— 6		Hand		None	do.	do.	
Do.	A few rods SW.	C. K. Poindexter	4	129	100±				do.	Hard and iron.	Easily pumped dry.	do.	do.	
Point Leavell	20 rods SE.	O. T. Wallace	4	70	25	None.			do.	Sulphur	None	Winchester	Stock.	

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Harrison County.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls*						
Berry	1 block W	Berry	6	130	120	None.	−24	2	Hand		None	Lexington	Domestic, stock.	
Do	1 block S	J. W. Haley	6	85	78	None.	−40	30	do		Lowered when pumped.	do	do	
Boyd	2 blocks SE	J. S. Baskett	6	100	90		−60			Hard; gas with water.	None	do		
Do	½ mile W	J. H. Knox	4	70	60	None.	−40		Hand	Hard	Low in dry weather.	do	Stock	
Claysville	3½ miles SW	George B. Duckworth.	6	117	100+		− 0		do	Hard; some sulphur.		do		Never used.
Do	¼ mile NW	Foster McDowell	6	131	65		−25	2	do	Hard; sulphur.	None	do	Domestic, stock.	
Colville	¾ mile S. of E.	L. W. Diltz	6	90	75–80	20	−10		Force	Hard; sulphur and oil.	do	do	Drinking, stock.	
Cynthiana	1½ miles N	A. Keller Distillery.	6	160			−14		Hand	Hard; sulphur.		do		
Do	¾ mile N	F. S. Ashbrook Distilleries Co.	8	280	90–100		−15		Steam	Hard; slight sulphur.	None	do	Manufacturing.	
Do	3 blocks SE	W. M. Cox	6	70	45	None.	−30		Gasoline engine.			do	Domestic, stock.	
Do	2 blocks S	J. W. Daniel	6	90			−30		Hand	Hard; some sulphur.	None	do	Boilers, manufacturing.	The amount of sulphur increases in dry weather.
Do	4½ miles NW	S. O. Ecker	6	119	119	30–40	−59	4	do	Hard; slight sulphur.		do	Domestic, stock.	
Do	4½ miles S	Edgewater Distillery.	6	168	140–150		+ 8			Sulphur water at 100 feet; less at 168 feet.		do	do	
Do	4 miles W	John K. Gray	6	120	No water.							do		No water.

Do	4 miles SE	M. S. McKee	6	150	100	20	−10		Hand	Hard; sulphur; tastes of oil.	Slight	do	Drinking, stock.	Tastes of oil.
Do	3½ miles E	M. J. Rankin	6	90	80	None.				Sulphur water; gas.		do		Not used.
Do	3 miles SE	Wohlender Bros.	6	74+	68	None.	−35	8+	Hand	Slight sulphur.	None	do	Drinking.	
Hooktown	1½ miles NW	Wm. Florence	6	88	25		−30		Force	Gas; salt	Lowers	do	Domestic.	
Jacksonville	200 yards E	J. Rose	6	98	81	16	−48		Hand	Strong sulphur water.	Slight	do	Drinking, stock.	
Lair	Across river E.	Edgewater Distillery.	6	150	125				Steam	Sulphur	None	do	Manufacturing.	Distillery abandoned.
Do	do	do	6	175	125				do	do	do	do	Drinking, manufacturing.	Do.
Do	do	Old Lewis Hunter Distillery	6	110	90	None.	−50		do	Some sulphur.	do	do	Manufacturing.	
Leesburg	1½ miles SE	R. J. Lucas	6	68		10, 20, 60	−12		Hand	Hard	In dry weather gets below −50 feet.	do	Domestic.	
Paris	8 miles NW	J. Crombie	6	70	68		−48		do	Sulphur	None	do	Stock	
Henry County.														
Eminence	⅛ mile SE	Charles S. Knight	6	68					do	Hard		Maysville	Domestic.	
Jessamine County.														
Brannon	2 miles NW	William Sale		60				½	Force	Iron		Lexington	do	
Camp Nelson	200 yards +N.	Kentucky Distilleries and Warehouse Co.	8	100					Steam	Hard	Lowered 7 or 8 feet.	do	Manufacturing.	
Do	8½ miles south of Nicholasville.	do	6, 8	196			−20	100	Air lift	Mild black sulphur water.		Below Highbridge.	do	
Hano	1½ miles S	H. B. Sand	6	74	70	None.	−34		Hand	Hard	None		Stock	
Keene	3 miles E	J. J. Gormley	6–4½	152	115	50	−50		Deep well and windmill.	Slightly sulphur.		Lexington	Drinking, stock.	
Do	2½ miles NE	R. R. Henderson.	4	100	99	None.	−57	0	Hand	Strong sulphur water; salt.		do	Domestic, stock.	
Do	2 miles N	Wharton Brothers.	4	80			−55		Hand	Sulphur		do	do	
Nicholasville	4 miles SE	City	4	85	85	None.	−6		Wooden suction.	do	None	do	do	
Do	3¾ miles SE	J. W. Cobb and Steven Snowden.	5½–4	80	80	18	−5	6	Hand suction.	do	do	do	do	

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Jessamine Co.—Cont'd.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Nicholasville	8½ miles NW.	R. R. Henderson.	5-4	100	99	None.	−57	.....	Hand	Sulphur; soft	.....	Lexington	Domestic, stock.	
Do	100 feet N.	Jessamine County.	5-3	110	100	60-80	−20	10	Deep well	Hard	None	...do	...do	
Do	50 yards S.	...do	4	120	120	.....	−20	.....	...do	...do	...do	...do	...do	
Do	1,400 feet N.	C. A. Kenney	6	77	62	.....	−22	25	Steam	Fairly hard	None	...do	Domestic, stock, boilers.	
Do	3 blocks N.	...do	6	75	62	50	−20	27	...do	Hard	...do	...do	Domestic, boilers, manufacturing.	
Do	...do	C. A. Kenney Laundry.	8	75	62	50	−20	14	...do	...do	...do	...do	...do	
Do	50 feet S. of C. A. Kenney's.	Nicholasville Ice Co.	8	71	62	None.	.....	.....	.....	.....	.....	...do	Ice plant	
Do	2½ miles W.	Nicholasville Water Co.	8	130	65	.....	− 3	200	Air lift	Hard	.....	...do	Domestic, stock, boilers, manufacturing, irrigation.	
Do	...do	...do	8	135	65	.....	− 6	200	...do	...do	.....	...do	...do	
Do	.....	W. D. Sharp	.....	75	.....	.....	.....	.....	.....	Salt, iron, sulphur.	.....	Highbridge	Drinking	
Wilmore	10 rods S.	City	4±	100	.....	.....	.....	.....	Hand	Hard	.....	...do	Domestic, stock.	Supply small.
Do	2½ miles NE.	Stephen Grow	4	140	.....	.....	.....	.....	Windmill	Sulphur	.....	...do	Domestic, stock.	
Do	⅛ mile SE.	.....	4	62	.....	None.	−15	.....	Hand	Hard	.....	...do	...do	

Kenton County.													
Bromley	2 blocks SW.	G. H. Hackladt.	6	90	60			1	do	Hard; some sulphur.	None	Alluvium	do	
Do		C. Lagee	6	70	18			1	do	do	do	do	Drinking, stock.	
Do		William Shafer	6	71	60			1	do	do	do	do	do	
Do		Webber	3	80			−30				do	do	Domestic, stock.	
Covington		Bavarian Brewing Co.	6,8	69–73	62		−60	50	Cook, McGowan, Laidlaw-Dunne.	Hard; some sulphur.	Lowers	do	Manufacturing.	
Do	3 blocks S.	John Brenner Brewing Co.	8	80	60		−50	100	Steam	Hard; slight sulphur.		do	do	
Do	2 blocks NW.	Cincinnati Ice Co.	8	200	65		−40	250	Air lift	do		do	do	
Do	S.	Consumers' Ice Manufacturing and Cold Storage Co.	4–8	110	80		−75	182	Dunne-Gordon.	do	None	do	Drinking, manufacturing.	
Do	Central avenue and Dayton street.	John Hancks Brewing Co.	8	140–165			−60	80+		Hard	do	do	Manufacturing.	Several wells.
Do		New England Distilling Co.	8	110			−20		Laidlaw-Dunne-Gordon.	Hard; some sulphur.	do	do	Manufacturing, irrigation.	
Latonia	½ mile E.	Latonia Distillery.	4	1,100	1,000					Strong sulphur.	do	St. Peter	Drinking, manufacturing.	
Do		Latonia Ice Co.	8,6	105	90+	Beds of sand.	−25		Steam	Hard	do	Alluvium	Manufacturing.	Uses 2 wells for cooling.
Do	1 mile S.	George Smith		275										No water.
Madison County.														
Paint Lick	500 yards NE.	R. N. Beasley	6	51	51	None.	− 5			Salt alkaline		Lexington		Too salt to use.
Richmond		Cooperage plant		300	40	do				Hard		Maysville		Small supply.
Mason County.														
Dover	In village	Dover City	3	70-85					Hand	do		Alluvium	Domestic, stock.	
Do	1 mile N.	Fred Kelch	2	60					do			do	do	
Do	¼ mile S.	Henry Schubert	6	157	65		−20		do	Iron		do	Domestic, stock.	

TABLE 8.—*Wells in the Blue Grass region*—Continued.

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Mason Co.—Cont'd.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Dover	1¼ miles SE.	Wilson Smith	1¼	70	55		−55	6	Hand	Moderately hard.	Unaffected when pumped 5 gallons per minute.	Alluvium	Domestic, stock.	
Do	6 blocks S.	J. J. Thomas	2	80	60		−60	10	do	Hard	Unaffected when pumped 10 gallons per minute.	do	do	
Do	1 block SE.	W. H. Thomas	2	76	65		−55–60	10	do	do	do	do	Domestic, boilers, stock.	
Fernleaf	3 miles E.	E. C. Slack	6	98	95+	None.	−27	Few.	Hand, windmill.	do	Slight	Maysville	Domestic, stock.	Slight odor of petroleum.
Maysville	Same block	R. A. Carr	7–8	108					Steam	do		Alluvium	Boilers, manufacturing.	
Do	1 mile E.	Pearce Foster	8	91, 92	40	16 to bottom.	−40	20	do	do	Unaffected when pumped 20 gallons per minute.	do	do	2 wells.
Do	4 miles N.	Elisha Moran	6	70	70	35	−35		Force	do		do	Drinking, stock.	
Do	3 blocks E.	William Sprom-burge.	3	75				30	Steam	do	None	do	Drinking, washing.	
South Ripley	Across railroad W.	Chesapeake & Ohio Ry.	2(?)	80	65		−65		Hand	Hard; brackish.		do	Drinking.	
Tuckahoe	1 mile W. of S.	John E. Bouldin.	6	315	315	20	− 3			Soft				Not used.

Mercer County.														
Burgin	1 block SW	Gillam & Tully	5½	60	50				Force	Hard	None	Lexington	Manufacturing.	
Do	do	J. W. Gilliam	5½	90	80±				Steam	do		do	Drinking, boilers.	
Do	½ mile	Public	8	40–100			−20 to −80		Force	do		do	Domestic, manufacturing, stock.	
Harrodsburg	2 miles E	Brown & True	5		90	90	−20		Windmill	Hard; black sulphur.	None	do	Drinking, stock.	
Do	do	William Brown	5	90	90	None.	−20		do	Hard; strong sulphur.	do	do	do	
Do	2 miles N	George Chinn	6	85	75				Hand	White sulphur water.		do	Domestic, stock.	
Do	3½ miles E	Scott Covert	5	103			−63		do	Hard	None	do	do	
Do	4 miles S	Judge John Hughes.		97			−10			White sulphur water.		do	Stock	Inexhaustible.
Do	3½ miles S	do		101	101		− 2	50±		do		do	do	
Do	½ mile NW	Ice factory	3¾	55	Near bottom.	10		80	Steam	Hard	Lowers	do	Boilers, manufacturing.	
Do	1¼ miles SW	Minor L. Ransdell.	5	85	40±	None.	−40		Hand	do	None	do	Drinking, stock.	
Do	½ mile NW	John B. Thompson's Distillery.	6, 4	35 or 40			−15 to −20	100+	Steam	do	Varies	do	Manufacturing.	
Kirkwood	1 mile SE	California-Kentucky Oil Co.	8¼–6¼	1,400	15		−35		do	Mineral	None			Not used.
Nevada		Schoolhouse		85	80				Hand	Hard; sulphur		do	Drinking	
Salvisa	⅛ mile S	G. H. Fallis	6½–6	90	60	None.	−60			Salt and sulphur.		do		Do.
Do	At	F. I. James	6	68	65	None.	−62		Hand	Hard		do	Domestic, stock.	
Do	⅓ mile SE	do	6	72	72	None.			Force	do		do	do	
Do	1 mile N	D. E. Nichols		110					Hand	do		do	Stock	
Do	500 yards NW	H. J. Trimble	4	65					Suction	Salt and iron		do	Domestic, stock.	
Do	¼ mile N	K. S. Wood	5, 7	86, 52	48				Hand, windmill.	Hard	None	do	do	
Nicholas Co'y.														
Carlisle	SE	Carlisle Milling Co.	6	155	150			3	Steam		do	do	Domestic, stock.	Not used except in dry weather.
Do	1,500 feet SE	City	6	135	40 or 50				Force	Hard		Winchester	do	

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Oldham County.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Beards	1 block W	Public well	6	50	40	50	− 12	½ to 1	Hand	Hard	None	Panola	Domestic, stock.	
Do	½ block N	M. A. Stoess	6	50	20	None.			do	do	do	do	do	
La Grange	¼ mile S	J. W. Barrickman.		1,200	1,200					Sulphur			Drinking	
Do	4 blocks E	Stock Company.	6	1,000	Dry hole.									
Do	3 blocks E	do	6	1,500	1,200	1,100	− 25							
Pewee Valley		Mrs. L. T. Cleland.	6	65	45	None.			Hand	Hard		Panola	Domestic	
Do	1 block W	Foley Bros.	6	60	25	40+				do		do	do	
Do	200 yards NE	Kentucky Confederate Veterans' Home.	6	200	−23	None.	− 23		Hand	do	Lowers	do	do	
Pendleton Co'y.														
		J. M. Booher	6	90	85	21			Force	Salt		Lexington	Stock	
Boston Station	½ mile S	Mollie A. Edwards.	8-6	1,600	800	None.				Iron and sulphur.		St. Peter	Drinking, stock.	
Robertson Co'y.														
Mount Olivet	2½ miles S	D. R. Wells	5	54			− 30		Force	Hard		Winchester	Drinking, stock.	
Do		John W. Zoller	6	103	80	36, 59, 80	− 24		Hand	do			Drinking	
Piqua	200 yards SE	W. J. Curtis	4	68	30	None.	− 27	7	do	Hard; some sulphur.	None	Winchester	Domestic	
Scott County.														
Donerail	1¼ miles W	Sidney S. Moore	4	127			− 80		Force	Mild sulphur	None	Lexington	Domestic, stock.	
Georgetown		Judge Askew	5	70	70				Hand	Hard		do	do	Large supply.
Do	1 mile N	do	4	127	127		− 37		Windmill		None	do	do	
Do	1 mile NE	John H. De Garis.	8-6	700			− 12			Sulphur				Not used.
Do		Warren Dennis	6	90+	85	28	− 45		Gasoline engine.	Hard	None	Lexington	Domestic, stock.	
Do	1 mile S	Georgetown Cemetery.		92					do	Hard; some sulphur.		do	Stock, irrigation.	

Do	6½ to 9 miles N.	Buford Hall	3	59, 57, 160			− 40±		do	Hard; sulphur.		Winchester (?).	Stock	
Do	do	do	3	70, 50+			− 40±		do	do		do	do	
Do	4 miles NW	Norman Hambrick.	8	100	93	None.	− 65		Hand	do	Large supply.	Lexington	Domestic, stock.	
Do	4 miles N	Uriah Hambrick	4½	98		None.	− 18		do	Sulphur	None	do	do	
Do	1 mile N	Nuns of Visitation.	12	107	107		− 20	60		Slight sulphur.		do	Domestic	
Do	1 mile S	R. B. Thomas	4	141	137	None.	− 55	6	Windmill.	Hard	None	do	Stock	
Do	1 mile SW	do	4	141	141	None.	− 85		do			do	Drinking, stock.	
Newtown	2 miles W. of S.	H. S. Booker	5	65			− 12	2	do	Hard, sulphur.		do	Domestic, stock.	
Do	2½ miles E	Elbert Hall	6	180	180	None.			Hand	Soft		do	do	
Do	1½ miles W	Reuben Offutt	6	112	100	None.			do	Sulphur		do	Stock	
Do	100 yards E	Public well	7	70	65	None.	− 30		do	do		do	Domestic, stock.	
Do	100 yards W	George D. Sallee	6	50	35	None.	− 30		do	Hard	None	do	Domestic, stock, boilers.	
Do	do	do	6	70	60	None.	− 40		do	do	do	do	Domestic, stock.	
Do	75 yards E	H. D. Williams	6	57	50	40	− 30		do	Sulphur	do	do	do	
Paynes Depot	3 miles NE	J. C. Cantrell	4	133	120			60		Hard		do	do	
Sadieville	30 yards SW	Town	6	188			−112	3+	Hand	Hard, iron, sulphur.		Winchester	do	
Stamping Ground.	5½ miles NE	D. S. Alsop	4	106	100	15	− 26		do	Salt and sulphur.		Lexington	Drinking, stock.	
Do	4 miles NW	J. O. Fluke	5	110						Hard, strong sulphur.		do		
Do	2 miles NW	Joseph Foree	5	70	60	None.	− 53		do	Hard, sulphur.	Large supply.	do	Domestic, stock.	
Do	2 miles NE	John T. Noel	6	60	52	None.	− 18		do	Strong sulphur.		Winchester (?).	do	
Do	1½ miles NW	do	5	60	52	None.	− 18	6	do	do	None	Winchester	do	
Do	2½ miles NW	Dr. R. S. Payne	5	70	65	None.			do	Hard		Lexington	do	
Do	Opposite center.	George D. Sallee	6	60	55	None.	− 25			do	Slight	do	Drinking	
Do	¼ mile E	do	6	85	80	None.	− 25		Hand	do		do	Domestic	
Shelby County.														
Shelbyville	1¾ miles W	John A. Middleton.	4½	155	90	None.			do	do		Maysville	Drinking	Well dynamited, but no increase in supply.
Do	2 blocks SW	Shelbyville Steam Laundry.	5	60	15	None.		1+		do	Varies	do	Washing, manufacturing.	
Simpsonville	2 miles W	Claude Buckley	5½	225		None.	− 25					do		Not used.

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Trimble County.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Cottage Hill	1 mile E	Z. T. Bore	6	81	50	50	− 15		Hand	Hard			Drinking, stock.	
Milton	½ mile S	Willis Barth	6	96+	44		− 12		do	do		Richmond	Domestic, stock.	
Do	½ block N	City	3	80+	35		− 35		do	do		Alluvium	Domestic	
Do	3 miles E	Dr. S. E. Hampton.	4	86	66		− 66±	5	Windmill	do	None	do	Drinking, stock.	
Do	3 blocks NE	A. W. Lane	3	80+	40		− 20	5	do	do	do	do	Domestic, irrigation.	
Do	2 blocks E	J. W. Lane	3	80					do	Moderately hard.		Richmond	Domestic, manufacturing, stock.	
Do	3½ miles W	H. N. McIntire	6	96	40	None.	− 40	4	Deep well	do		do	Domestic, stock.	
Do	4 miles S	R. M. Overton	6-5	80	60		− 20		Suction	do		do	do	
Do		Richwood Distillery, H. M. Levy.	5, 6, 8	96±	65		−60 to −65		Steam	do		do	Boilers, manufacturing.	
Do	2½ miles E	Charles Schurmeier.	6	56	49		− 26		Hand	Hard; slight sulphur and salt.	Lowered slightly.	do	Stock	
Do	½ block N	Trimble Milling Co.	4	80					Steam	Hard	None	do	Boilers	
Wodford County.														
Frankfort	5 miles S	W. A. Gaines & Co.	6	779						Hard; salt, sulphur.	do	Highbridge	Drinking, stock	
Jett	2½ miles S	Pat O'Brien	6	60	20	40	−30 to −40		Windmill and gasoline engine.	Hard		Lexington	Domestic, stock.	

Do	1 mile S	Mrs. V. Thompson.	5	60	60		— 30		Hand	do		do	Domestic	Lowered in dry weather.
Do	do	do	5	89	89		— 50		do	do		do	Stock	Never dry.
Midway	2 blocks SE	Belle of Anderson.	6	96	96		— 20	20	Steam	Hard; some sulphur.			Manufacturing.	
Do	4 blocks W	City	4	90	70				Force	Hard	None	Lexington	Domestic	
Do	Across street, Main street.	do	4	95					Hand	Some sulphur		do	do	
Do	5 blocks W	do	4	100								do	Domestic, stock.	
Do	2¼ miles S	Frank H. Hawkins.		110						Salt		do	Stock	
Do	3 blocks SW	D. Lehman	4	102						Hard		do	Domestic, stock.	
Do	3½ blocks W	R. J. McMullen		95						Sulphur		do	Stock	
Do	2¾ miles S	Nugent Bros	6	118	118		— 58		Hand	Hard; sulphur		do	Drinking	Sold for medicinal purposes.
Millville	2 miles N	E. B. Cutt	5	59			Varies,			Hard		do	do	
Mortonsville	¾ mile N	J. G. Boone	6	50+	48	None.	— 30	18	Hand	do	Unaffected when pumped 18 gallons per minute.	Highbridge	Domestic, stock.	
Do	At north	Ed. Boston	6	51	49	None.	— 33	20+	do	do	Unaffected when pumped 20 gallons per minute.	do	do	
Do	½ mile W	Marion Johnson	5	53	50	13	— 38		Force	Sulphur	None	do	Domestic, stock.	
Do	do	E. S. Sillard	6	115	75	40	— 35			Hard		do		Gas at 50 feet; never used.
Do	50 yards E	Dr. S. C. Sublett	5 or 6	75					Hand	Sulphur		do	Drinking	
Do	A few rods east.	Dr. S. Q. Sublett	6	68	68				do	Hard		do	Drinking, stock.	
Nonesuch	300 yards S	J. R. Bond	4	65	45		— 45		Bucket	do		do	Domestic, stock.	
Pinckard	½ mile N	W. Sippert	5	85	80	30+	— 37		Hand	Hard; sulphur	None	Lexington	do	
Spring Station	3 miles SE	A. J. A. Alexander.		86	86	None.	— 86		Windmill	Hard		do		Not used.
Do		do	4–3	95	95				Deep well, windmill, and gasoline engine.	do		do	Drinking, stock.	Do.

TABLE 8.—*Wells in the Blue Grass region*—Continued.

Post-office.	Direction and distance from post-office.	Owner.	Diameter of well.	Depth of well.	Depth to principal supply.	Depth to other supplies.	Height of water above (+) or below (−) the surface at well.	Yield per minute.	Kind of pump.	Quality of water.	Effect of pumping on supply.	Geologic horizon of water beds.	Use.	Remarks.
Woodford Co.—Cont'd.			*In.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*						
Spring Station.	2 miles SE.	A. J. A. Alexander.	....	140	140	None.	−110	.....	.....	Strong white sulphur.	.....	Lexington.	.....	Not used.
Do.	3½ miles W.	Thomas W. Hackney.	5	200	200	100	−100	.....	Elevator.	Salt, sulphur.	.....	....do.....	Medicinal.	
Versailles.	1 mile NW.	Charles Alexander.	5	90+	90+	.....	.....	.....	Windmill.	Hard, sulphur.	Weak stream.	....do.....	Domestic, stock, irrigation.	
Do.	½ mile E.	J. C. S. Blackburn.	5	124	.....	.....	.....	.....	Gasoline engine.	Sulphur.	None.	....do.....	Washing, stock.	The water contained both salt and sulphur. The sulphur has gradually disappeared.
Do.	800 feet N.	J. Andrew Cain.	4¼	134	132	65	− 70	20	Steam.	Lime, magnesia, and zinc, alkaline.	...do.....	....do.....	Drinking, stock.	
Do.	2 miles N.	J. N. Camden, jr.	5	190	170	60	− 70	.....	Windmill.	Hard.	.....	....do.....	Domestic, stock.	
Do.	....do.....	....do.....	5	200	175	60, 100	.....	.....	...do.....	Hard, sulphur.	.....	....do.....	...do.....	
Do.	100 feet W.	City.	6	90	.....	.....	.....	.....	.....	.....	.....	....do.....	.....	
Do.	.....	Fair grounds.	.....	104	102	32	.....	.....	Hand.	Hard.	.....	....do.....	Drinking, stock.	
Do.	4 miles N.	Jesse Graddy.	2½–6	62	10	30	− 32	.....	Force.	Limestone.	Lowered some.	....do.....	Domestic, stock.	
Do.	½ mile NW.	A. T. McLeod.	5	149+	.....	30	.....	18	Gasoline engine.	Hard.	None.	....do.....	Domestic.	
Do.	½ mile S.	Joe S. Minary.	5	163	160	.....	− 80	.....	Hand.	Hard; slight sulphur.	...do.....	.....	Stock.	
Do.	½ mile SE.	H. P. Morancy.	....	130	130	None.	−130	.....	Force.	Hard.	.....	Lexington.	Domestic, stock.	Medicinal.

Do	½ mile NW	G. B. Mosely	5	101	96	26	— 50	15	Force and gasoline engine.	do	None	do	do	
Do	4 miles SE	J. W. Newman	6	134	120				Hand	do		do	Domestic.	
Do	¼ mile N	C. L. Ryley	5	180	170	75		70+	Gasoline			do	do	
Do	150 yards W	Shotwell Bros	5	75	40	26	— 26	85+	Steam	Hard	None	do	Domestic, stock, boilers, manufacturing.	
Do	¼ mile S	H. C. Taylor	5	128	120	40	— 40		Gasoline engine.	Sulphur water		do	Domestic, stock.	
Do	2 blocks S	Thompson-Childers-Minary Co.	5	93	50	20	— 40		do				do	
Do	½ mile NW	I. W. Wilson	5½	98	92	30			Suction	Hard	None	Lexington	do	

QUALITY OF THE UNDERGROUND WATERS IN THE BLUE GRASS REGION.

By Chase Palmer.

INTRODUCTION.

In the summer of 1903 the writer undertook an investigation of the quality of the waters of Kentucky River in cooperation with the United States Geological Survey. The tests were continued for one year, during which period a similar study was made of the headwaters of Dix, Green, and Salt rivers, which rise in the upland near the southern limits of the Blue Grass region. A few results of this early study of Kentucky and Dix rivers are presented in this report to illustrate the hardness of two important surface streams of the Blue Grass region in comparison with that of the underground waters.

In the spring of 1905, under a similar arrangement, field assays of waters from wells and springs were made in several Blue Grass counties, and the results of that work are also embodied in this report.

In July, 1906, a more extended investigation of the underground waters of the Blue Grass region was begun, jointly with George C. Matson, of the Geological Survey. The subsurface waters from a much larger area were subjected to complete chemical analysis at Lexington, Ky., and the results of the examinations are recorded in the table of analyses on page 212.

ACKNOWLEDGMENTS.

Thanks are due to Dr. M. A. Scovell, director of the Kentucky Agricultural Experiment Station at Lexington, for affording the facilities of the chemical laboratory of the station, so that the analytical work could be carried on expeditiously within the State. It is also desired to express to Dr. A. M. Peter, chemist of the experiment station, appreciation for his uniform courtesy and hospitality while the chemical work of this investigation was in progress. The publications of the Kentucky Geological Survey and of Kentucky Agricultural Experiment Station have been consulted and use has been made of the information contained therein and originally obtained by Dr. Robert Peter and Dr. A. M. Peter, chemists of those two state institutions, respectively.

INDUSTRIAL USES OF WATER.

IMPORTANCE OF QUALITY.

The quantity of water used in modern human industry is so vast, its applications are so varied, and its essential characteristics are so distinctive that water may be considered the most important mineral used in the industrial arts. Immense quantities of water are necessary for many manufacturing operations. Every pound of writing paper made, for instance, has required the use of no less than 40 pounds of water, and in some paper mills as much as 1,600 pounds. In selecting a location for a paper mill, therefore, it is important to see that a liberal supply of water is assured.

The quality of the water best suited for use in any particular industry is also a matter of considerable moment. An iron-bearing water can not be used in a bleachery without previous purification. A calcic carbonate water is undesirable in leather making, as it causes brown stains on the hides and may also produce a reddish leather which has a low market value. The manufacture of tanning and dyewood extracts is another important industry involving the use of enormous quantities of water. These extracts, being easily fermentable, do not keep well if made with polluted water, or water containing putrefactive bacteria.

In the arid regions of the West the scarcity of water makes it a high-priced commodity which is valued accordingly; in the East, where a plentiful supply of water may usually be obtained, little attention was formerly given to its quality, on which its real value so largely depends. Eastern manufacturers have, however, begun to realize that water used in the manufacture of products for which its quality is unsuited is expensive. Its cost may not appear in the price paid for it, but is apparent rather in the smaller yield of the products which it has helped to make, or in the low prices which they command when put upon the market. The benefits derived from the use of water which is naturally suited for a specific purpose or which has been properly treated to meet the requirements of a special operation are quickly realized in the increased quantity and value of the products obtained.

STEAM MAKING.

The engine which turns into mechanical work the energy possessed by steam has given to water a new industrial value, and the rapid advance of modern civilization is due largely to the use of water as a motive power in the form of steam. Steam making may be regarded as an industry in which the raw material is water and the finished product is steam. The quality of the water used in the boiler is of interest to the engineer because upon it the profitable production of steam in large measure depends. The life of the boiler also is in no

small degree determined by the care taken to supply it with proper feed water. With a noncorrosive water which does not form hard scale a stationary boiler may last thirty to thirty-five years, but a corrosive water may make it useless in five years. Prevention of corrosion means protection of the boiler; prevention of scale means saving of labor, repairs, and fuel.

CORROSION AND SCALE.

The use of impure water in a steam boiler results usually in corrosion and the deposition of scale. Many waters, especially spring waters, that are comparatively free from mineral matter in solution are known to be strongly corrosive when used in steam boilers. Free acids, such as hydrochloric, sulphuric, and nitric, are very corrosive, attacking iron easily, and waters containing them must therefore be neutralized before they can safely be used for steam making. Water showing no sign of acidity before it enters the boiler sometimes develops corrosive properties when it is heated. Water containing magnesium chloride in solution, for instance, may be neutral under ordinary conditions, but at high temperatures and under increased pressure of the boiler hydrolysis occurs, forming free hydrochloric acid, which vigorously attacks the boiler shell and tubes. The magnesium oxide also formed in this action finds its way to the boiler shell where it may add itself to any scale there forming.

Scale is an incrustation deposited within the boiler during the evaporation of hard waters. The scale from calcic carbonate waters is loose and can be removed by blowing off. Calcic sulphate waters, on the other hand, form a hard tenaceous scale, the removal of which is sometimes very difficult. Hard scale conducts heat poorly, so that a hotter fire is necessary to keep up steam in a boiler thus coated. A waste of 15 to 20 per cent of fuel has been known to be caused by hard scale only 7 to 8 millimeters thick. Boilers thus overheated are liable to blister and to crack, and many serious explosions have resulted from overheating scale-lined boilers.

SALUTARY EFFECT OF SCALE.

Though a thick, hard scale is detrimental to a boiler, a thin coating of scale is often distinctly advantageous. This is especially noticeable where corrosive waters are used for making steam. Kent[a] calls attention to the fact that rain water, and even melted snow, cause pitting of the plates and more or less general corrosion. As a protection against the ravages of waters of this kind he recommends the occasional addition of a little limewater, so that a thin coating of scale may be formed. In certain parts of the United States, especially

[a] Kent, William, Corrosion produced by rain water in steam boilers: Eng. News, vol. 52, 1904, p. 198.

in the West, the waters available for use in locomotives are not only hard but are also high in sulphates of the alkali metals. The usual practice has been to soften such waters before use by precipitating the calcium and magnesium with soda ash, and the formation of scale is prevented by this treatment, but at the same time an equivalent amount of alkaline sulphates is added to the water. Excessive quantities of alkalies in water cause foaming, and on western railroads waters softened in the manner just mentioned have made much trouble. The harder a water is before it is softened by soda ash, the larger is the quantity of alkali sulphates in the water after treatment, and consequently the greater is its tendency to foam in the boiler. M. E. Wells[a], chief boiler inspector of the Burlington and Missouri River Railroad, deprecates the practice in vogue on several railroads of softening such waters for locomotive use by adding soda ash. He quotes the following figures to show the increase in alkalies caused by treating with sodium carbonate a water used by the Chicago and Northwestern Railway from a well 70 feet deep at Council Bluffs, Iowa:

Result of treating water with sodium carbonate.

	Parts per million.
Incrustants:	
Before treatment	813
After treatment	66
Nonincrustants, mostly alkalies:	
Before treatment	106
After treatment	472

Here a hard incrusting water is changed to a foaming water. Wells states that on the Burlington and Missouri River Railroad better results are obtained with incrusting than with foaming waters. He also recommends the use of limewater as a substitute for caustic soda to remove calcium and magnesium from alkaline carbonate waters, because limewater causes no addition of alkali to the water. According to Wells, a moderate amount of scale serves to protect boilers, and this impression seems to be gaining ground among engineers who are compelled to use hard, alkali sulphate waters for steaming.

The sulphate water used in the boilers of the Hoffmann distillery, in Anderson County (see Table 14, p. 201) would probably form hard scale if precautionary measures were not taken. The boilers are cleaned frequently, care being taken to let them cool before washing them, and the scale is easily detached. The scale is not allowed to become thick or to bake into a hard, difficultly removable crust. The water from this well was used continuously during two long runs aggregating thirty-five months, and affords an excellent illustration

[a] Wells, M. E., Foaming waters and scaling waters for locomotive boilers: Eng. News, vol. 52, 1904, p. 198.

of the favorable results that may be obtained from a hard water if intelligent care is exercised in its use.

ACTION ON BOILERS OF ORDINARY CONSTITUENTS OF WATER.

Silica and iron are both found in boiler scale and may be regarded as incrustants. Silica, however, causes very little trouble, as it is present in water in very small quantities, and the same may be said of iron, although iron derived from corrosion of the boiler is sometimes added to the scale. Aluminum also is an incrustant present in most waters in quantities so small that it is not necessary to consider it; but when too much aluminum sulphate, a substance frequently used as a coagulant in filtering water, is added in the process of filtering, the excess passes through the filter and may cause trouble in the boiler, where it hydrolyzes, forming free sulphuric acid. Sodium carbonate will correct the acidity due to an excess of aluminum sulphate, and it can be used to precipitate the aluminum as a harmless solid. Barium carbonate is a better remedy, but it is too expensive for general use. Owing to the poisonous quality of barium compounds, their use should probably be restricted to waters intended only for industrial purposes.

Calcium is the chief constituent of both hard and soft scale, but a water containing as much as 50 parts per million of calcium may be used under certain conditions without bad results. Carbonate waters containing as much as 150 parts of calcium per million might profitably be softened, but carbonate waters with that amount of calcium are usually also high in sulphates and chlorides, and it is doubtful whether such waters can be successfully treated for boiler use.

Magnesium is an incrustant appearing in boiler scale as magnesium oxide, hydroxide, and carbonate. This metal accompanies calcium in waters, but the calcium usually predominates. Magnesium can be economically removed from magnesic carbonate waters containing less than 60 parts per million of magnesium. Magnesic chloride and sulphate waters are highly corrosive because they are easily hydrolyzed in the boiler, forming respectively free hydrochloric and sulphuric acids.

The alkali metals, sodium, potassium, and lithium, are all found in water, but only sodium occurs in quantities large enough to merit consideration. As compounds of the alkalies are readily soluble they can form no permanent scale, but on the other hand they are easily hydrolyzed, forming free acids which corrode the iron. Alkali carbonate and alkali sulphate waters have, moreover, a tendency to foam and thereby interfere with the uniform production of steam. No method is known by which alkalies may be economically removed,

so that their presence in any water in large quantity is a permanent detriment to its use in boilers.

The bicarbonate radicle (HCO_3) in carbonate waters is usually related to calcium and magnesium. These metals are supposed to be held in solution by the bicarbonate radicle, appearing respectively as $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$. When a calcic magnesic carbonate water is heated the equilibrium of the two soluble constituents is disturbed; carbon dioxide (CO_2) escapes with the steam, and calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) are deposited. The calcium carbonate, soon after it is formed, becomes crystalline and incapable of adhering firmly to hot iron, so that water containing considerable quantities of these bicarbonates, unaccompanied by other incrusting constituents, may be used without danger of forming a hard crust on the boiler.

Carbon dioxide (CO_2), whether present in the free state in the water or released by the decomposition of bicarbonates, is not without corrosive action on iron. It has a tendency to cause pitting of the boiler, so that highly carbonated waters are treated more effectively before they enter the boiler than afterwards. Lime water added in proper quantity to carbonate waters eliminates both calcium and magnesium as well as the bicarbonate radicle. After allowing time enough for the precipitate to settle, the softened water may be fed to the boiler. Carbonate and bicarbonate waters of the alkalies, that is, waters containing the carbonate and bicarbonate radicles in equilibrium with sodium, are occasionally found in Kentucky and in other States farther west. When these waters are heated the alkaline carbonates react chemically with the alkaline earth constituents, causing removal of the latter. Chlorides in water are simply corrosive. Excessive amounts of chlorides are undesirable, and waters containing over 100 parts per million of chlorine are unsuitable for boiler use. Organic matter causes foaming and sometimes it acts corrosively. Its corrosive action is due to the formation of free organic acids to which iron is susceptiible.

Calcic sulphate waters deposit a hard scale, the chief component of which is calcium sulphate. Magnesium sulphate waters are objectionable because they not only corrode the boiler by producing free sulphuric acid in the water, but they also deposit magnesia in the scale, thereby increasing its hardness and making it very refractory. As sulphates of the alkalies, besides hydrolyzing and causing corrosion, also induce foaming in boilers, large quantities of such sulphates are undesirable. No perfectly satisfactory method has yet been devised for removing the sulphate radicle from waters of this character.

Deep-seated waters are usually so highly mineralized that they corrode iron rapidly or form scale in boilers; occasionally, however,

such waters are found to be very satisfactory. The water from a well at the Lexington station of the Cincinnati Southern Railway (analyses 23 and 24, p. 212) affords a good illustration of a highly mineralized deep water containing also correctives of hard scale.

This water was found on analysis to contain sufficient calcium, magnesium, and sulphates to form a hard, refractory scale under ordinary conditions, but it was also charged with carbonates of the alkalies. The analyst, Dr. Robert Peter, predicted that these carbonates would precipitate the incrustants in powdery form, thus preventing the deposition of calcium sulphate as a hard scale on the boiler shell,[a] and his assertion that the water could be used in boilers without harmful effect was verified by experience. Another example of water of similar character is furnished by the well at Hope Mills. This well, 134 feet deep, yields water from two horizons, one at a depth of 65 feet and the other at 132 feet. During wet weather, while the 65-foot stream flows, the water forms hard scale in the boilers; during dry weather, when the water is drawn from the lower stratum, the scale formed is soft. The water from the 132-foot vein is not only soft but is said to loosen boiler scale caused by the hard water from the upper vein. Water from a well at Paint Lick, in Madison County (analysis 56, p. 214), though much more highly mineralized than that from the well of the Cincinnati Southern Railway at Lexington, has been used for many years in a steam boiler without forming much scale. The presence of carbonates of the alkalies in the water at Paint Lick probably accounts for the small amount of boiler scale. A well water in Gallatin County (analysis 49, p. 212) illustrates the character of waters found in some places in the alluvium. It contains 16 parts per million of sulphates—a quantity which should cause little trouble in boilers—and it carries also carbonates of the alkalies which precipitate the incrustants, so that when heated the water should completely soften itself and should form no bad boiler scale.

CORRECTIVES OF SCALES.

Hard scales formed by sulphate waters may be prevented by treating the waters with certain substances which precipitate the incrusting constituents in a loose, powdery condition. Sodium carbonate, an agent frequently employed for this purpose, precipitates the calcium as calcium carbonate, which forms a loosely adhering scale if the water is treated after it enters the boiler. As soda ash does not remove the sulphate radicle, the presence of which is undesirable in boiler water, the use of this chemical is only a partial remedy in waters naturally forming hard scale. Barium

[a] Peter, Robert, Well water: Geol. Survey Kentucky, vol. 5, new ser., 1880, pp. 188-190.

chloride may be used instead of sodium carbonate in the treatment of sulphate waters. Although this compound causes the precipitation of the sulphate radicle in a form that does not produce scale, it leaves chlorides in the water, and owing to their corrosive action, high chlorides are undesirable in boiler waters. Barium carbonate is especially suited for removing iron, aluminum, and sulphates from waters, but it is rather too expensive for general use. Hard carbonate waters are most satisfactorily softened by means of milk of lime, which precipitates both calcium and magnesium in powdery form.

Not uncommonly scale preventive is added to the water in the boiler, but it is always better to soften water in tanks before it enters the boiler and to allow sufficient time for the precipitate to settle. Water softened in this way is used to better advantage in making steam, and the boiler is relieved of the extra duty of serving as a water-softening plant.

Many specifics for preventing and removing boiler scale are on the market, some of them being helpful, but others of little value, though the vendors use persuasive arguments in presenting the merits of their wares. Care should be exercised, however, not to use the wrong kind of boiler compound, as more harm may be caused by it than by the untreated water itself.

SOAP MAKING.

In the processes most commonly used soap is made by the chemical action of soda lye (caustic soda) on melted fat. The soap, being easily soluble, is dissolved by water as soon as it is formed, so that a fresh layer of fat is exposed uninterruptedly to the soda-lye solution. The value of soap as a cleansing agent is due to the fact that it forms in water a solution capable of producing suds; therefore anything that changes soap into an insoluble substance reduces just so far its value as a cleansing agent. Hard waters—calcium and magnesium waters—produce with ordinary soap a curdy precipitate of calcium and magnesium compounds that are insoluble in water and incapable of forming suds, and consequently are valueless as cleansing agents. If hard water is used in soap making the calcium and magnesium present react with the soap as soon as it is formed, making an abundant precipitate, which retards the further action of the soda lye on the fat and wastes soap. The precipitate will continue to be formed at the expense of the soluble soap until the calcium and magnesium in the water are entirely removed. Small quantities of the hardening constituents of water can decompose a large quantity of soap.

One requisite, therefore, for a large yield of soap is soft water. If hard water is the only kind available for soap making, it should be

softened before use in the works; if not softened beforehand, it will be softened afterwards by the soap, and soap is an expensive water softener.

Sodic chloride waters are undesirable in soap making, because soap is not soluble in solutions of sodium chloride, and briny waters also prevent the free access of the lye to the melted fat. Indeed, advantage is taken of the insolubility of soap in brine when it is desired to remove the soap from solution. Salt is added to the soap solution and the soap then separates out as a solid mass.

Clear water must be used in the manufacture of soap. Suspended matter of all kinds must be removed from the water by filtration to insure the production of a pure, fine-grained product.

LAUNDERING.

The development of the steam-laundry industry has been rapid in recent years, and public service of this character is becoming more and more general. The most important laundry supplies are water and soap, for the combined cost of all other materials consumed in scouring, brightening, and sizing is less than the total cost of soap and water. The prudent launderer buys high-grade soap, because he knows that not only are better results obtained with soap of good quality than with that of inferior grade, but also that his soap bill is correspondingly reduced. It is just as important in laundering to use water of good quality as it is to use good soap. The water should be clear, soft, and free from iron and suspended matter. If the water is muddy or turbid it must be filtered before it can be used.

After the goods are received at the laundry they are soaked in cold water for a short time to remove stains and loosen the starch. At the end of the soaking period steam is admitted to raise the water to the boiling point, the necessary quantity of soap is added, suds are formed, and the washing begins. If the water is hard a wasteful expenditure of soap takes place at this stage. The calcium and magnesium in solution react with the fat acids of the soap, precipitating the insoluble curdy soaps of calcium and magnesium. No suds are formed, and the whole operation of cleansing is delayed until the calcium and magnesium are completely precipitated.

The loss of soap is not the only evil effect of hard water. The precipitated earthy soaps act as coagulants, seizing mechanically upon impurities which are thus often deposited on the fiber of the goods. These plasters adhere to the goods, appearing finally as greasy spots on the laundered material. Hard water is therefore undesirable for laundry use, economically as well as æsthetically.

The water used in all stages of the cleansing process must be as free as possible from iron, as brown stains on the finished product are

likely to result from the use of water containing iron to the extent of even one part per million.

The hardness due to calcium and magnesium bicarbonates may be removed by a judicious use of lime water, but the permanent hardness is not reduced in this way. Soda ash (sodium carbonate) is well suited for this purpose, and may be applied after the water has been treated with lime. Hardness due to compounds of calcium and magnesium other than the bicarbonates is thus removed. After sufficient time has been allowed for settling the clear water may be used for washing. The tendency of waters containing alkalies to foam in boilers—a feature that makes carbonates of these metals so undesirable in feed water—is of decided advantage to the laundry water. Carbonates of the alkalies are said to "thicken" the soap, increasing its power to emulsify oily material, thus adding to its cleansing qualities. For this reason the usual practice is to add sodium carbonate to the water with the soap merely to strengthen the soap.

The hardness of water is usually expressed as parts per million by weight of calcium carbonate; water having a hardness of 100 parts per million, for instance, is understood to be water containing 100 pounds of calcium carbonate in 1,000,000 pounds of water. Theoretically 100 pounds of calcium carbonate require for removal 61 pounds of high-grade commercial quicklime, 112 pounds of soda ash, or 860 pounds of soap. Assuming the cost of these reagents to be, quicklime, 0.3 cent; soda ash, 1.25 cents; and soap, 5 cents per pound, the cost of softening a quantity of water containing 100 pounds of calcium carbonate would be, with quicklime, $0.18; with soda ash, $1.40; with soap, $43.

Whipple[a] has experimented on waters of different degrees of hardness to determine their effect on the quantity of soap used in bathing and for general household purposes. He finds that 1 pound of the average soap used in the household will soften 167 gallons of water having a hardness of 20 parts per million. This is equivalent to about 5,990 pounds of soap per million gallons, which, at a cost of 5 cents a pound, would amount to $300 per million gallons. He also finds that the cost increases about $10 per million gallons of water softened for each increase of one part per million of hardness.

It is often asked whether the quantity of soap consumed by a hard water is an item of expense worthy of serious consideration in laundries, which require daily many thousands of gallons of water in which soap is used. This question is best answered by a practical illustration. Let it be assumed that a laundry is using daily 10,000 gallons of water having a hardness of 96 parts per million—the average hard-

[a] Whipple, G. C., The value of pure water: Wiley & Sons, 1907, p. 24.

ness of Kentucky River below Tyrone. According to Whipple's experiments, the hard water causes a loss of average soap amounting to about $10.70 a day. In three hundred working days the annual consumption of soap by the hard water alone would amount to $3,210. If, however, the water were previously softened with lime to reduce its hardness to 30 parts per million (the average permanent hardness of the river), then the daily cost of soap consumed by the laundry water would be only $4.10. After adding to this amount 1 cent for the lime required for the softening, the total daily cost of the partly softened water becomes approximately $4.11. This partial softening of the water, therefore, results in a saving of soap cost of $6.59 a day, or a total annual saving of $1,977. No claim is here made for the absolute accuracy of these figures in estimating the cost of softening water. The size and capacity of the softening plant, cost of labor and fuel, attendance at the works, difficulties arising from turbidity, variable content of magnesium, and other conditions of the water to be softened, must be considered. The computations indicate, however, that there is much room for economy by softening the water before its use, and they suggest, moreover, the practicability of installing mechanical devices to make the natural water more economical in its consumption of soap.

ICE MANUFACTURE.

The rapid gain in popular favor which artificial ice has made in this country in recent years is shown by the reports of the United States Census. In 1870 there were in the United States only four ice factories, with a total capitalization of $434,000, and the total ice output for that year was valued at $258,250. In 1905 reports were recived from 1,320 establishments, indicating a capitalization of $66,592,001, and the total output of ice was valued at $23,790,045. These figures do not include 163 establishments engaged primarily in manufacturing other products, which are reported to have made $1,899,912 worth of ice.

It is important that the water used in the manufacture of ice for household purposes and for cooling beverages should meet all the requirements of potable water in respect to cleanliness and freedom from organic matter and disease germs. Most American manufacturers use distilled water in making ice, in order to get a pure, transparent product.

Two systems are employed in making artificial ice in this country. These are the can and the plate systems. Though cakes of ice frozen from impure water by the can system may be for the most part clear, the center of the block is likely to be opaque. Drown[a] has shown that the interior of the block contains most of the impurities that

[a] Drown, T. M., Ann. Rept. Massachusetts State Board of Health, 1892, p. 592.

were originally distributed through the water. At a certain ice factory known to the writer the core containing the concentrated impurities is cut from the block and allowed to melt, and the liquid product is served to the employees as a preventive of intestinal disorders! It is needless to say that this ice factory is not in Kentucky.

In the plate system, which is becoming more and more popular in this country, it is not necessary to use distilled water in order to obtain clear ice if suitable appliances are installed to prevent the occlusion of air and solid particles. Though it is true that the greater part of the bacteria and mineral matters in the raw water are excluded from the frozen plate, there is insufficient ground for assuming that perfectly harmless ice can be made directly from dangerously polluted water. And while it may be conceded that water pure enough for drinking is pure enough for making ice, it is nevertheless true that too much dependence should not be placed upon the natural purifying powers of the freezing process.

Water serves another purpose in the ice factory beside that of being the raw material for the ice and the steam. Much heat is absorbed by the ammonia which has been used for freezing the water, and advantage is taken of the cooling effect of water to assist in recovering the exhaust ammonia for subsequent use. In the compression system the pipes containing compressed gaseous ammonia are surrounded by cold water constantiy flowing in large tanks, or the cold water is sprinkled directly upon the ammonia pipes. In both processes the water absorbs heat from the ammonia, changing it from the gaseous to the liquid form. Water charged with incrustants deposits on the hot ammonia pipes a scale closely resembling the scale formed by the same water in a boiler. Sometimes this scale is very hard and tenacious, and if it is allowed to remain on the pipes, it may become so thick as practically to nullify the cooling effect of the water.

BREWING AND DISTILLING.

The water used in breweries should receive careful attention, because the quality of the beer depends largely upon the quality of the water. In general, a good potable water, free from color, odor, and decomposing organic matter may be used to advantage for brewing. Clean water is indispensable in a brewery. Waters polluted with sewage or putrefactive bacteria should be avoided, for they prevent the beer from keeping well and give it a disagreeable taste. Great care must also be taken to use perfectly clean water in washing the kegs and barrels in which the beer is to be stored. Organic matter in the water is objectionable, as it is likely to promote the growth of mold in the barley, thus preventing a proper development of diastase in the malted grain. In the later stages of the brewing

process organic matter in the water is undesirable, because it not only lessens the activity of the yeast, but also forms putrefaction products that seriously affect the quality of the beer.

Water used in brewing should be as free as possible from iron, which combines directly with diastase, forming an insoluble compound and thus reducing the efficiency of the ferment; moreover, iron waters impart an unpleasant taste to the beer. Iron may be removed from water easily and cheaply by forcing air through the water and then filtering it through sand and gravel. The iron hydroxide, which is precipitated by the aeration, is retained completely on the filter. Sodic chloride waters, if not too strong, favor the development of diastase and are therefore of decided advantage in malting. Magnesic chloride waters act similarly. On the other hand, calcic chloride waters are to be avoided because they retard the development of yeast. Calcic and magnesic sulphate waters, which are undesirable for boiler supplies, soap works, and certain other industries, are of distinct advantage to the brewer. Such waters assist the development of the yeast and produce beers of agreeable flavor and good keeping qualities. Soft waters dissolve from the hops a resin which darkens the color of the beer. Calcium sulphate waters do not dissolve hop resin, and thus produce a light-colored beer. Many brewers who have no supply of natural calcium sulphate waters treat with calcium sulphate the waters used in fermentation, regulating the quantity of the mineral to the kind of beer to be brewed.

Table 9 shows the amounts of some of the important constituents in the waters used in brewing three famous kinds of beer—the light Burton ales, the dark Dublin porters, and the beer of the Hofbräuhaus in Munich. Probably the chemical composition of the water supplies influences the essential characteristics of these beverages.

TABLE 9.—*Composition of waters used for brewing.*

[Parts per million.]

	Burton-on-Trent, England.	Dublin, Ireland.	Munich, Germany.
Iron (Fe)		2	Trace.
Calcium (Ca)	370	100	72
Magnesium (Mg)	88	3.7	53
Sulphate (radicle (SO_4)	895	44	55
Chlorine (Cl)	34	16	35

In distilleries the malting and fermenting processes are carried much farther than in brewing. What has been said regarding the effects produced by waters of different kinds in brewing applies with equal force to the corresponding processes in a distillery; but

since the object of the distiller is to get the largest possible yield of alcohol from the grain, it is important that the water used in the fermentation vats should contain in proper quantities only those substances which are favorable to a vigorous growth and a high efficiency of the yeast plant. The waters of the Blue Grass region, which have long been recognized as being specially suited for making whisky, also produce beer of superior grade.

COMPARATIVE HARDNESS OF BLUE GRASS WATERS.

Economically, hardness is an important quality of water, whether it is used industrially or in the household. The chief difference in the character of the hardness of underground and river waters of the Blue Grass region lies in the excessive alkalinity of the ground water, while the permanent hardness of the water in the lower part of Kentucky River and in Ohio River at Cincinnati closely approximates the permanent hardness of the waters of the Lexington limestone and of the alluvial deposits. The hardness of 16 waters from springs and shallow wells occurring in the Lexington limestone and from 7 wells in the alluvium of Ohio and Licking rivers is shown in Tables 10 and 11. The alkalinity was determined in the regular course of analysis, while the permanent hardness has been calculated from the amounts of calcium and magnesium in the form of salts other than carbonates. The figures indicate that the alluvial waters are somewhat harder than the waters of the Lexington limestone, both in respect of permanent hardness and of alkalinity.

TABLE 10.—*Hardness of the water from springs and shallow wells in Lexington limestone*

[Parts per million as $CaCO_3$. Analyst, Chase Palmer.]

No. (a)	County.	Locality.	Owner.	Source.	Alkalinity.	Permanent hardness.	Total hardness.
1	Anderson	Tyrone		Spring	224	22	246
2	do	do		do	226	35	261
20	Fayette	Lexington	Ed. Kane	Well	189	33	222
21	do	do	Aug. Belmont	Spring	234	24	258
22	do	do	Boice Grogan Co	Well	286	37	323
26	do	do	W. W. Estill	do	295	46	341
28	do	do	W. M. Field	Spring	136	20	156
32	do	do	Harkness	do	189	6	195
36	do	do	Mrs. Israel	Well	232	18	250
37	do	do	Lexington Brewing Co	do	233	18	251
40	do	do	J. E. Pepper	Spring	194	14	208
41	do	do	do	Well	238	40	278
42	do	do	Pettit	do	166	40	206
66	Scott	Georgetown	Askew	do	197	41	238
68	do	Stamping Ground.	Distillery	Spring	177	9	186
74	Woodford	Versailles	Brodhead	Well	198	24	222
	Average				213	27	240

(a) These numbers refer to the numbers of the analysis in the table on pp. 212-215, from which additional details may be obtained.

TABLE 11.—*Hardness of water from alluvial wells.*

[Parts per million as $CaCO_3$. Analyst, Chase Palmer.]

No. (a)	County.	Locality.	Owner.	Source.	Alkalinity.	Permanent hardness.	Total hardness.
5	Boone	Petersburg	Boone County Distillery	90 ft. well	235	43	278
8	Bracken	Augusta	Electric Light Co	90 and 50 ft. wells.	361	55	416
9	do	do	Steam laundry	80 and 60 ft. wells.	287	20	307
12	Carroll	Carrollton	Furniture factory	Well	306	28	334
49	Gallatin	Warsaw	do	do	296	0	296
53	Kenton	Covington	Cincinnati Ice Co	do	332	51	383
71	Trimble	Melton	Richwood Distillery	do	235	23	258
	Average				293	31	324

a These numbers refer to the analysis numbers in the table on pp. 212–215, to which reference is made for further details.

The following table gives the amounts of hardening constituents found in Ohio River water at Cincinnati under varying conditions and at different stages of the river:

TABLE 12.—*Hardness of water from Ohio River at Cincinnati, Ohio.*

[Parts per million as $CaCO_3$.]

Authority.	Conditions.	Alkalinity.	Permanent hardness.	Total hardness.
G. W. Fuller[a]	Normal for 1898	45	33	78
Do[a]	Average (March 13–April 25) 1899	40	29	69
J. W. Ellms	March 21, 1902 (high water)	21	21	42
Do	September 16, 1902 (low water)	72	41	113
Average		44	31	75

a Purification of the Ohio River water, Cincinnati, 1899, p. 493.

During the period from August, 1903, to June, 1904, the waters of Kentucky River were studied by the writer at monthly intervals Eight stations were established along the river at convenient shipping points, the highest station being at Jackson, in Breathitt County, and the lowest at Worthville, in Carroll County. The collections at all stations were made from midstream except those at the Government locks at Highbridge, Tyrone, and Frankfort. The samples from the waterworks at Frankfort were collected at the intake. In this way it was sought to secure typical samples of the river water from its head waters in Breathitt County along its entire course.

TABLE 13.—*Average hardness of water from Kentucky River, August 20, 1903, to June 3, 1904.*

[Parts per million as $CaCO_3$.]

	Alkalinity.	Permanent hardness.	Total hardness.
Jackson (11 months)	32	18	50
Beattyville (11 months)	33	19	52
Irvine (11 months)	36	26	62
Highbridge, Lock No. 7 (9 months)	55	27	82
Tyrone, Lock No. 5 (9 months)	67	33	100
Frankfort waterworks (10 months)	66	31	97
Frankfort, Lock No. 4 (10 months)	66	30	96
Worthville (11 months)	67	30	97

During the same period a similar study was made of the quality of the headwaters of Dix River at Gum Sulphur in Rockcastle County, showing alkalinity, 78; permanent hardness, 18; and total hardness, 96 parts per million as $CaCO_3$.

The progressive increase both in alkalinity and in permanent hardness in the water of Kentucky River from the mountains at Jackson until after it passes Irvine is noteworthy. The initial alkalinity of Dix River at its source in the upland of Rockcastle County is higher than the alkalinity of Kentucky River at any point in its course, and the sudden increase in the alkalinity of Kentucky River at Highbridge is probably due largely to the mingling of the more highly alkaline waters of Dix River, which enters Kentucky River a short distance above the lock at that place. Dix River is evidently an important factor in determining the mineral character of the water of lower Kentucky River, because the new degree of permanent hardness and alkalinity acquired by Kentucky River, shown by the results at Tyrone, remains practically constant throughout the rest of its course in the Blue Grass region until the Kentucky unites with the Ohio.

FIELD ASSAYS OF WATER.

During the spring of 1905 a series of assays of water from wells and springs in the Blue Grass region was undertaken to obtain general information concerning the industrial value of the underground waters in the district. An assay of water is not a complete chemical analysis, because the determinations in an assay are confined mainly to those constituents which are regarded as having an important bearing on the fitness of a water for special purposes. The methods used in making the assays are in general those devised for the U. S. Geological Survey by Leighton.[a]

[a] Leighton, M. O., Field assay of water: Water Supply Paper U. S. Geol. Survey No. 151, 1905.

Field determinations of the constituents of waters are not altogether a novelty. As early as 1854 Dr. David Dale Owen, director of the first Geological Survey of Kentucky, made many tests of waters in the field. Recognizing at that early period the importance of gaining positive information concerning the water resources of the Commonwealth, he provided himself with chemicals and apparatus for making quick tests of water. He carried these with him on his expeditions, and was thus enabled to ascertain on the spot the important characteristics of many waters of the State. In this way a much wider area was covered than would otherwise have been possible, and though the field examinations were merely qualitative, much information concerning the waters of Kentucky was obtained at a minimum cost.

When the samples of water were taken by the writer for field assay, the records of the wells were obtained and as much information as possible was gathered concerning the character of the rock through which the borings were made. Seven counties in the Blue Grass region were visited, and the results of the assays made in these counties are given in Table 14. The estimated incrustants probably approximate the total incrustants in these waters. Considering the sulphates as forming hard scale, these waters are classified in a general way according to a scale suggested by the American Master Mechanics' Association for classifying waters for locomotives boilers. Though this classification has not been generally adopted, it serves fairly well as a means of judging, within tolerably wide limits, the fitness of a water for steam making. The classification refers in no wise to the value of these waters for ordinary domestic purposes.

Classification of waters.

Incrustants:	
Below 250 parts per million	Good.
250 to 350 parts per million	Fair.
350 to 500 parts per million	Poor.
500 to 700 parts per million	Bad.

Of the 60 waters represented in the table of assays, 25 are designated good, 18 fair, 16 poor, and only 1 water is apparently so highly mineralized as to be considered unsuitable for boiler service. These results indicate that the waters in the region covered by the investigation are fairly good for industrial uses, and that with preliminary treatment they may profitably be softened so as to yield favorable results in steam boilers.

TABLE 14.—*Field assays of water in Blue Grass region.*

[Parts per million.]

Date.	County.	Location.	Owner.	Source.	Depth of well.	Depth of water.	Turbidity.	Color.	Iron.	Chlorine.	Sulphate radicle (SO_4).	SO_4 calculated to $CaSO_4$.	Alkalinity as $CaCO_3$.	Estimated incrustants.	Classification for boiler use.
1905.					*Feet.*	*Feet.*									
Apr. 12	Anderson	Hammond Creek	Hoffman Distilling Co.	Well	36	29	0	0	1.2	26	86	21	255	376	Fair.[a]
12	do	Lawrenceburg	City	3 wells	90	45	0	2	0	29	59	82	194	276	Good.[a]
15	do	County	Old Prentice Distillery	Well	65	60	0	4	0	55	Low.	50	265	315	Good.[a]
15	do	Lawrenceburg	Dowling Distillery	do	40	40	0	4	0	4	Low.	25	155	280	Good.
15	do	Tyrone	Waterfill & Frazier Distillery.	Spring			0	4	Trace.	17	59	82	259	341	Fair.
4	Boyle	Danville	Gentry & Kenney	Well	104	40	0	0	.2	93	127	178	279	457	Poor.
Mar. 4	do	do	Charles Orman	do	8	8	0	17	0	4	Trace.		71	75	Good.
3	do	do	Mrs. Emma Hazelton	do	60	50	0	4	.4	11	105	147	203	350	Poor.
3	do	do	Charles Hardesty	Spring			0	4	.3	58	13	18	197	215	Good.
16	do	do	D. F. Slavin	Well	125	125	0	7	.3	27			263	263	Good.
8	do	Forkland	A. B. Minor	do	27	26	0	6	.6	196	52	72	253	325	Fair.
8	do	do	T. M. Purdom	do	27	26	0	6	0	283	91	127	221	348	Poor.
8	do	Hankla	W. F. Powers	do	58		0	4	0	40	124	172	288	460	Poor.
16	do	Junction City	Mrs. W. T. Richardson	do	24	24	0	6	.1	97	31	44	102	146	Good.
7	do	Mitchellsburg	Town	do	25		0	9	.4	212	92	129	221	350	Poor.
8	do	Parksville	J. D. Minor	do	57		0	4	.3	762	97	136	190	326	Poor.
8	do	do	Lapp Ewing	do	100		0	2	.3	42	168	234	245	379	Poor.
1	do	Perryville	Town	do	47	47	0	4	.1	33	43	94	170	264	Fair.[a]
1	do	do	do	do	63	63	0	4	.3	30	66	93	192	285	Fair.[a]
1	do	do	J. W. Brogles	do	56	56	0	4	.2	13	55	77	189	266	Fair.[a]
4	do	Shelby City	J. S. Figg	do	22	22	0	7	.1	48	94	130	145	275	Fair.
Apr. 4	Garrard	Camp Dick Robinson	A. B. Montgomery	do	60	35	0	4	.3	6	25	35	118	153	Good.
Mar. 16	do	Boone Cave Spring		Spring			0	5	.2	8			84	84	Good.
13	do	Lancaster	Mrs. J. West	Well	8	7				44	83	116	129	315	Fair.
13	do	do	Walden Bros.	do	20		0	9	.3	71	22	30	296	326	Fair.[a]
Apr. 4	do	Marcellus	C. K. Poindexter	do	120	100	0	4	.1	57	71	99	156	255	Fair.[a]
May 20	Jessamine	Nicholasville	Town	do	120	120	2	2	.6	44	98	137	272	409	Poor.
20	do	do	C. A. Kenney	do	77	62	0	2	.5	54	113	127	2 6	393	Poor.
20	do	do	Speais & McKay	do	14	10	5	9	.3	17	42	59	188	247	Fair.
Mar. 29	Mercer	Harrodsburg	Old Jordan Distillery	do	35		0	3	.1	54	120	1 8	214	382	Poor.

[a] Faint odor of hydrogen sulphide.

TABLE 14.—*Field assays of water in Blue Grass region*—Continued.

Date.	County.	Location.	Owner.	Source.	Depth of well.	Depth of water.	Turbidity.	Color.	Iron.	Chlorine.	Sulphate radicle (SO_4).	SO_4 calculated to $CaSO_4$.	Alkalinity as $CaCO_3$.	Estimated incrustants.	Classification for boiler use.
1905.					*Feet.*	*Feet.*									
Mar. 29	Mercer	Harrodsburg	Electric-light plant (outside).	Well	25		0	4	Trace.	371	186	260	293	553	Poor.
29	do	do	Electric-light plant (inside).	do	23		0	0	0	11	43	60	176	236	Good.[a]
May 18	do	do	H. C. Smith & Sons	do	30		0	2	.1	19	50	70	206	276	Good.
18	do	do	G. W. Miles	do	35	35	10	2	.2	12	64	89	252	341	Fair.[a]
18	do	do	Allen & Buster	do	40	20	8	5	.2	47	113	147	203	360	Poor.
Apr. 26	Scott	Georgetown	J. N. Moreland	do	52	42	0	2	2	4	34	47	166	213	Good.
26	do	do	J. C. Porter	do	71	61	5	2	.5	9	30	42	172	214	Good.
26	do	Stamping Ground	Town (schoolhouse)	do	85	80	5	9	2.5	30	18	25	306	331	Fair.
26	do	do	Town (center)	do	60	55	5	9	2	111	43	60	327	387	Poor.
26	do	do	C. T. Duvall	do	40	35	0	4	1.2	27	61	85	179	264	Fair.
26	do	do	J. T. Noel	do	60	52	15	77	2	264	30	42	440	482	Poor.[b]
27	do	Newtown	Mrs. C. P. Pribble	do	59	54	10	6	2	278	83	116	252	368	Poor.
27	do	do	Public	do	48	40	10	4	2	80	30	42	261	303	Fair.[a]
27	do	do	H. D. Williams	do	57	40 and 50	0	19	8	42	30	42	224	266	Fair.[a]
27	do	do	G. W. Murphy	do	84	60	0	2	2	128	54	75	146	221	Good.[a]
27	do	do	Geo. D. Sallee	do	50	35	0	2	2	30	112	156	163	319	Fair.
27	do	do	do	do	70	60	0	2	2	55	124	169	414	583	Bad.
27	do	do	R. Offutt	do	112	100	0	4	8	479	24	34	166	200	Good.
May 19	Woodford	Midway	Town	do	90	70	0	0	.3	42	103	144	216	360	Poor.
19	do	do	do	do	160		0	2	.2	12	Trace.		216	216	Good.
19	do	do	M. C. Kaselbaum	do	80		0	2	.7	32	77	107	137	244	Good.
19	do	do	D. Lehman	do	102		5	2	.2	32	54	75	196	271	Fair.
1906.															
May 18	do	Versailles	Childer's Place	Spring			0	3	Trace.	6	24	34	88	122	Good.
18	do	do	D. M. Bowmar	Well	45		0	3	Trace.	12	35	49	178	247	Good.
18	do	do	Steam Laundry	do	57		0	4	Trace.	37	71	99	192	291	Fair.
18	do	do	J. T. Wilhoit	do	100		2	5	Trace.	9	50	70	145	215	Good.
18	do	do	Fair Grounds	do	107		0	24	Trace.	6	60	84	148	232	Good.
18	do	do	Edwards Spring	Spring			0	2	Trace.	9	35	49	88	137	Good.
18	do	do	Big Spring (town)	do			0	2	Trace.	9	35	49	92	141	Good.
18	do	do	Chapman	do			0	2	Trace.	9	35	49	88	137	Good.

[a] Faint odor of hydrogen sulphide.

[b] Black sulphur water.

MEDICINAL WATERS.

GENERAL CHARACTERS.

Kentucky has long been famous for the number and great variety of its mineral springs, many of which are located in and about the Blue Grass region. A few of the well-known medicinal waters of central Kentucky deserve special mention.

Bromide waters have been recommended as sedatives and have been used successfully in the treatment of epilepsy and ulcerous affections. Iodine is a more active alterative than bromine, though, like bromine, iodine is never present in waters in large quantities. Iodide waters often produce rapid cures and find extensive application in the treatment of a wide range of chronic diseases. The Lower Blue Lick spring waters and several other iodide waters acquired fame for the cure of goitre, scrofula, and other diseases long before it was known that they contained iodine. Bromine and iodine impart to water such valuable medicinal qualities that a list of well-known springs containing these elements is given here for comparison with some of the medicinal waters of Kentucky.

TABLE 15.—*Bromine and iodine in water from various sources.*

[Parts per million.]

	Bromine.	Iodine.
Deep sea water	2,077	.....
Average ocean water	414	.....
Congress Spring, Saratoga, N. Y.	115	2
Champion Spring, Saratoga, N. Y.	48	3.2
Franklin Lithia, Ballston, N. Y.	48	1.7
Sans Souci, Ballston, N. Y.	.....	20
Jordan Alum, Va.	.....	10
Iodin Spring, W. Va.	11	11
Brown's Magnesian Well, Independence, Kans.	182	1
Kreuznack, Germany	200	.9
Kissingen, Bitterwasser, Germany	99	.....
Lower Blue Lick, Ky.	23	.14
Upper Blue Lick, Ky.	51	.13
Salt Sulphur Spring, Olympian Springs, Ky.	13	Traces.

Sulphur waters are important medicinal agents, the sulphur obtained from them having a powerful effect on the liver, the mucous membranes, and the skin. An admirable description of the therapeutics of sulphur waters is given by Schweitzer,[a] who recognizes that the value of a sulphur water as a curative agent depends largely on the character of the sulphur compounds present. Free hydrogen sulphide, although, on account of its disagreeable odor, the most prominently noticeable sulphur constituent of water, appears incapable of entering the circulation, and leaves the body without having produced any material effect; on the other hand, the sulphides of the alkalies are readily taken up by the blood, where they release

[a] Schweitzer, P., Geol. Survey Missouri Rept., vol. 3, p. 36.

hydrogen sulphide, which under these conditions produces a powerful effect upon the entire system. In a medicinal sulphur water, therefore, the sulphur should be associated with elements other than hydrogen. The Blue Lick waters of Kentucky and the Stachelberg waters of Switzerland, to both of which reference is made in the following pages, are types of medicinal sulphur waters.

CRAB ORCHARD SPRINGS.

Sulphate waters are very common in the Blue Grass region. When they are strongly sulphated, and are also highly charged with magnesium, such waters acquire decidedly medicinal properties. Waters of this kind abound at Crab Orchard, in Lincoln County, and for this reason the Crab Orchard Springs have maintained their popularity as a health resort for more than half a century. The composition of the water from Sowder's Spring was determined by Dr. Robert Peter.[a] It is analogous to that of the world-famous water at Carlsbad, Bohemia. The following comparative table shows the composition of these two waters. The Carlsbad water is somewhat weaker than the Crab Orchard water, and it is also deficient in magnesium, to which the special virtue of the American spring may be attributed.

TABLE 16.—*Composition of water from Sowder's Spring, Crab Orchard, Ky., and from the Sprudel Spring, Carlsbad, Bohemia.*

[Parts per million.[a]]

	Sowder's (Peter).	Sprudel (Gottl.).
Silica (SiO_2)	12	144
Iron (Fe)	Trace.	1.9
Aluminium (Al)	.....	6.4
Calcium (Ca)	664	110
Magnesium (Mg)	969	16
Sodium (Na)	523	1,874
Potassium (K)	134	23
Bicarbonate radicle (HCO_3)	1,159	1,839
Sulphate radicle (SO_4)	3,666	1,898
Phosphate radicle (PO_4)	.....	23
Chlorine (Cl)	606	724
Bromine (Br)	Trace.	.....
	7,153	6,661

[a] Obtained by computation to ionic form; results originally stated in hypothetical combinations.

The action of the Crab Orchard waters is analogous to that of a simple solution of magnesium sulphate (Epsom salt), which is a strong cathartic. Physicians found in practice, at an early date, that the waters from these springs are not so severe in their effects as magnesium sulphate alone; they act rather as laxatives than as purgatives. It appears that the other constituents present in the natural waters so temper the magnesium and the sulphates as materially to

[a] Kentucky Geol. Survey, 1857, vol. 2, p. 239.

reduce their activity. Owing to the mildness of their action, the epsom spring waters are applicable to the treatment of a greater variety of diseases than is the case with the simple solution of magnesium sulphate.

The epsom spring waters of Crab Orchard have been used extensively in the manufacture of salts at one time sold as a cathartic. The composition of the salts from Sowder's Spring, as determined by Dr. Robert Peter,[a] shows the general character of the salts obtainable from the epsom springs of this locality.

Composition of salts from Sowder's Spring.

Magnesium sulphate	63.19
Sodium sulphate	4.20
Potassium sulphate	1.80
Calcium sulphate	2.54
Sodium chloride	4.77
Calcium, magnesium, and iron carbonates and silica	.89
Bromine	Trace.
Waste and loss	22.61
	100.00

KIDDVILLE EPSOM WATER.

A magnesic water bearing a close resemblance to the epsom waters at Crab Orchard occurs at Kiddville in Clark County (analysis 14, p. 212). The Kiddville magnesium water is more highly sulphated and contains magnesium and calcium in larger proportions.

OLYMPIAN SPRINGS.

Olympian Springs, in Bath County, have long been famous as a watering place, and the locality is still held in high esteem as a health resort. In general, the waters at Olympian Springs are distinctly ferruginous, and one water combines the qualities of a magnesic sulphate water with ferruginous properties. Among these springs are black-sulphur waters, white-sulphur waters, and a very strong salt-sulphur water. The salt-sulphur spring water, analyzed by Robert Peter in 1877,[b] was found to be alkaline and borated, and to contain as much as 13 parts per million of bromine and traces of iodine.

The Olympian Springs salt-sulphur water is used advantageously in the bath, and it is recommended as a valuable remedy in the treatment of skin diseases. A close resemblance between the quality of this Olympian Spring water and that of the Kaiserquelle at Aix la Chapelle was observed by Peter, and the composition of these two waters is reproduced for comparison.

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[a] Loc. cit.

[b] Kentucky Geol. Survey, Chemical Analysis A, vol. 1, 1884, p. 365.

TABLE 17.—*Composition of water from salt-sulphur springs at Olympian Springs, Ky., and Aix la Chapelle, Germany.*

[Parts per million.[a] Analysts: Peter (Olympian Springs) and Liebig (Aix la Chappelle).]

	Olympian Springs.	Aix la Chapelle.
Silica (SiO_2)	23	66
Iron (Fe)	1.2	4.4
Aluminum (Al)	.4	Trace.
Barium (Ba)	9	.....
Strontium (Sr)	2.6	.1
Calcium (Ca)	89	63
Magnesium (Mg)	42	15
Sodium (Na)	1,934	1,421
Potassium (K)	19	69
Lithium (Li)	.1	0.03
Carbonate radicle (CO_3)	Trace.	.....
Bicarbonate radicle (HCO_3)	329	1,023
Sulphate radicle (SO_4)	5.8	276
Chlorine (Cl)	3,081	1,599
Bromine (Br)	13	3.3
Iodine (I)	Trace.	Trace.
Borate radicle (B_4O_7)	Trace.	.....
Sulphide radicle (S)	Trace.	14
Organic matter	34	75
	5,584	4,628

[a] Obtained by computation to ionic form; results originally stated in hypothetical combinations.

ESTILL SPRINGS.

The Estill Springs, at Irvine, Estill County, are situated in one of the most picturesque localities of the State. Within easy reach of Kentucky River and close to the mountains, the surroundings are unusually attractive. A commodious hotel and well-kept grounds add to the natural advantages of the place. The several springs supply red-sulphur, white-sulphur, black-sulphur, and chalybeate waters, all of which, except the last, are reported to contain hydrogen sulphide. The iron is deposited from these waters soon after collection, so that their full virtue is realized only by treatment at the springs.

The red-sulphur water deposits ferric hydrate, the color of which has given the name to the water. Black ferrous sulphide is deposited from the black-sulphur water, and from the white-sulphur water a white deposit of sulphur is formed.

TABLE 18.—*Composition of Estill Springs waters.*[a]

[Parts per million.[b] Analyst, Dr. Robert Peter.]

	Red sulphur.	White sulphur.	Black sulphur.	Chalybeate.
Silica (SiO_2)	6.8	4.0	13	32
Iron (Fe)	.....	.....	48	15
Aluminum (Al)	.....	8.5	3.6	.....
Calcium (Ca)	81	121	45	148
Magnesium (Mg)	26	25	11	47
Sodium (Na)	99	52	26	7.4
Potassium (K)	42	32	7.6	4.9
Carbonate radicle (CO_3)	197	24	108	72
Sulphate radicle (SO_4)	176	152	67	350
Phosphate radicle (PO_4)	.....	Trace.	.....	.....
Chlorine (Cl)	5	5.5	22	5.5
Organic and volatile matter	40	50	59	141
	715	696	410	896
Free carbondioxide (CO_2)	325	360	263	269
Free hydrogen sulphide (H_2S)	4.5	3	35	0

[a] Geol. Survey Kentucky, 1st ser., vol. 4, p. 143.
[b] Obtained by computation to ionic form; results orginally stated in hypothetical combinations.

KEO-ME-ZU SPRINGS.

The Keo-Me-Zu Springs, located in Kenton County, about 10 miles south of Cincinnati, have recently attracted favorable consideration as affording excellent mineral waters. They consist of three springs, all of the alum-chalybeate variety, and are well charged with free carbon dioxide. The composition of the Keo-Me-Zu Spring waters is given in the following table:

TABLE 19.—*Composition of Keo-Me-Zu Spring waters.*

[Parts per million.[a] Analysts, Karl Langenbeck and Louis Schmidt.]

	Alpha Spring.	Bonanza Spring.	Climax Spring.
Silica (SiO_2)	26	90	15
Iron (Fe)	12	12	0.8
Aluminum (Al)	3.8	32	7.7
Manganese (Mn)	.....	.2	Trace.
Calcium (Ca)	115	282	167
Magnesium (Mg)	23	18	19
Sodium (Na)	63	20	22
Potassium (K)	7.7	2.1	4.6
Carbonate radicle (CO_3)	248	388	260
Sulphate radicle (SO_4)	125	370	114
Nitrate radicle (NO_3)	4.4	.....	.....
Chlorine (Cl)	7	6.5	2.2
Organic and loss	.....	2.2	Trace.
	632	1,257	610

[a] Obtained by computation to ionic form; results originally stated in hypothetical combinations.

LOWER BLUE LICK SPRINGS.

These celebrated saline-sulphur springs, located near the north bank of Licking River in Nicholas County, were known to the first settlers of Kentucky. The Indians and the pioneers of the State were in the habit of visiting the springs in order to procure the salt with which their waters were richly impregnated. The medicinal virtues of these waters were also recognized at an early date, and they have been regarded as efficacious in the treatment of scrofula, chronic rheumatism, gout, engorgements of the liver, and chronic skin diseases.

The first quantitative analysis of the Lower Blue Lick waters was made by Robert Peter, and the report of the first Geological Survey of Kentucky, published in 1850, contains an interesting account of his elaborate investigation of the composition of these remarkable spring waters. Several important characteristics of these waters were disclosed by this early study. They were found to be not only strongly saline, but alkaline, and to have the additional value of being moderately strong alkaline sulphated waters. The presence of bromine and iodine was also discovered, and quantitative determinations of these two elements were made.

This early analysis includes also determinations of the gaseous constituents of the waters. Free carbon dioxide and hydrogen sulphide dissolved in spring waters begin to escape as soon as the water

is exposed to the air, and, in order to ascertain the quantities of these two gases present in the water when it reaches the surface, it is necessary to make the determinations at the spring.

By the improved volumetric methods and with the modern appliances now in daily use, determinations of these gases may be made in the field as rapidly and as accurately as in the chemical laboratory. At the time, however, when this analysis was made, such refinements were unknown, and the manner in which Peter was enabled to ascertain the exact quantities of hydrogen sulphide and carbon dioxide present in the waters at the fountain head exemplifies his resourcefulness in procuring accurate chemical results under the most unfavorable conditions.

The method used by him was to add to a measured volume of the water at the spring a solution of a chemical capable of acting at once upon the gas, forming with it an insoluble powder; then to seal the bottle and subsequently to determine in the laboratory the quantity of the precipitate formed in the water at the spring.

The hydrogen sulphide was fixed by means of a solution of arsenious acid in hydrochloric acid, and the carbon dioxide was similarly precipitated as calcium carbonate by an ammoniacal solution of calcium chloride.

A second analysis of the Lower Blue Lick waters was made by Peter in 1877. The object of his examination at this later date was to ascertain whether these waters had undergone any essential change in their character during the twenty-seven years since the first analysis, and to discover, if possible, the presence of elements more rarely occurring in waters. The second analysis developed the fact that the waters had suffered no material change since the time of the first analysis, and disclosed the presence of minute amounts of barium, strontium, and lithium, also notable quantities of borates and alkaline sulphides, the latter indicating that sulphur is present in these waters in at least two different conditions. The results of this analysis appear in the second column of Table 20.

According to a recent classification of mineral waters proposed by Haywood, the Lower Blue Lick water may be designated as a sodic, muriated, saline, alkaline (sulphide), borated (bromide, iodide), carbondioxated, sulphureted water.

The alkaline sulphide character of the Lower Blue Lick water is comparable with that of the water of the Stachelberg Spring in Switzerland, one of the famous healing springs of Europe. On account of its remarkable curative power, its waters have been prescribed by physicians ever since the latter part of the eighteenth century. The analytical results of an exhaustive study of the

Stachelberg Spring water, made in 1854 by Simmler,[a] are reproduced in the sixth column of Table 20. To simplify the comparison of the waters of these springs, the results obtained by Simmler are reduced to ionic form. Simmler observed that the quantity of sulphur in the form of hepatic sulphur, or alkaline sulphide, in the Stachelberg water is not constant, but varies within tolerably wide limits. For instance, he found that the sulphur present in the alkaline sulphides on four different occasions was, summer 1853, 57; winter 1853; 54; spring 1854, 63; summer 1854, 61 parts per million. The Stachelberg Spring water contains notable quantities of this sulphide sulphur, which makes this water still more powerful as a sulphur water; though the Stachelberg water contains more absorptive sulphur than has been observed in the Lower Blue Lick, the latter is far more highly mineralized and appears to have additional curative power on account of other saline constituents.

For several years past the supply of Blue Lick waters for shipment is reported to have been obtained from a spring on the south side of Licking River. In 1900 A. M. Peter made partial analyses of the waters obtained simultaneously from the Old Spring on the north bank and of the New Spring on the south bank of the river. The results of these analyses, recorded respectively in the third and fourth columns of Table 20, indicate that, although the waters from both springs appear to be somewhat weaker than the waters of the Old Spring were in 1877, they still possess the same general characteristics, even in regard to the presence of alkaline sulphides, by which both samples were colored slightly yellow. Although the alkaline sulphides are more permanent than hydrogen sulphide in water, they decompose gradually unless the water is kept in tightly sealed bottles. In the fifth column of the same table is reproduced an analysis of a sample of the Lower Blue Lick water which had been kept about three years in a wooden barrel.[b] The results of this analysis demonstrate the inadequacy of wooden containers to preserve the alkaline sulphides for any great length of time, for at the time of the analysis every vestige of hydrogen sulphide and of the alkaline sulphides had disappeared, indicating that during the storage in wood the water had wholly lost the medicinal qualities which are peculiar to an alkaline sulphide water. The Blue Lick waters are applicable to the treatment of so many diseases that they have a wide range of usefulness.

[a] Simmler, Theodor, Comprehensive study of the Stachelberg Spring water: Jour. prak. Chemie, old ser., vol. 71, 1857, p. 1.

[b] Haywood, J. K., Mineral waters of the United States: Bureau of Chemistry, U. S. Dept. of Agri., Bull. 91, p. 50.

TABLE 20.—*Composition of water of Lower Blue Lick Springs, Kentucky, and of Stachelberg Spring, Switzerland.*[a]

[Parts per million.]

	Old Spring, north bank of Licking River.			New Spring, south bank of Licking River.		Stachelberg Spring (Simmler 1854).
	R. Peter, 1850.	R. Peter, 1877.	A. M. Peter, 1900.	A. M. Peter, 1900.	J. K. Haywood, 1905.	
Silica (SiO_2)	14	12	.....	.....	18	9.7
Iron (Fe)	[b] 5.8	[b] 3.8	.....	.....	1	.....
Aluminum (Al)			.....	.....	1	1
Manganese (Mn)	Trace.	.....	.....	.....	2.6	.....
Calcium (Ca)	317	307	302	308	343	40
Magnesium (Mg)	135	133	132	133	179	44
Barium (Ba)	.....	.1	.....	.....	.....	.....
Strontium (Sr)	.....	.5	.....	.....	.....	.....
Sodium (Na)	3,289	3,324	2,746	2,812	2,718	80
Potassium (K)	80	98			81	1.9
Lithium (Li)	.....	1			1.8	.6
Ammonium (NH_4)	.....	.....	.....	.....	.8	.....
Bicarbonate radicle (HCO_3)	473	434	.....	.....	412	278
Sulphate radicle (SO_4)	474	390	413	380	340	100
Nitrate radicle (NO_3)	.....	.....	.....	.....	2.2	.....
Nitrite radicle (NO_2)	.....	.....	.....	.....	Trace.	.....
Borate radicle (B_4O_7)	.....	23	.....	.....	Small.	.....
Phosphate radicle (PO_4)	Trace.	Trace.	.....	.....	Trace.	3.6
Chlorine (Cl)	5,462	5,558	4,925	5,120	4,900	3.4
Bromine (Br)	3.4	17	.....	.....	23	.....
Iodine (I)	.6	.3	.....	.....	.14	.....
Alkaline sulphides (S)	.....	13	Present.	Present.	(c)	58
Thiosulphate radicle (S_2O_3)	.....	.....	.....	.....	.....	12
Organic and loss	282	457	427	377	1.4	84
Total solids	10,296	10,558	9,026	9,315	9,022	580
Hydrogen sulphide (H_2S)	39	28	34	16	(c)	2.2
Carbon dioxide (CO_2)	355	(c)	.....	.....	257	114

[a] Obtained by computation to ionic form; results originally stated in hypothetical combinations.
[b] Includes ferric and aluminic oxides and calcium phosphate.
[c] Not reported.

UPPER BLUE LICK SPRINGS.

The waters of the Upper Blue Lick Springs, which are also situated in Nicholas County, closely resemble the waters of Lower Blue Lick. They are recommended as remedies for the same diseases as those for which the Lower Blue Lick water is prescribed. They are extensively sold.

TABLE WATERS.

In the territory covered by this investigation there are numerous other sources of wholesome water which might be made of commercial importance. Pure, safe water is wanted for table use in large cities, where a widespread prejudice exists against the city waters supplied from sewage polluted streams; and country districts, remote from congested population, are naturally regarded as the most favorable localities from which daily supplies of such water may be obtained. The ordinary pure spring waters of the Blue Grass, being but slightly mineralized, are well adapted for use as table waters, for, besides being palatable, they contain a moderate quantity of various

saline ingredients conducive to health, and have therefore a distinctly dietetic value.

The Anita Spring and Royal Magnesian Spring in Oldham County have already acquired considerable reputation as table waters in cities where their waters have been put upon the market. The composition of the waters of these two springs is given in the following table:

TABLE 21.—*Analyses of table waters from Anita and Royal Magnesian springs.*[a]

[Parts per million.]

	Anita (L. D. Kastenbein).	Royal Magnesian (A. M. Peter).
Silica (SiO_2)	16	7.6
Iron (Fe)	.4	.6
Aluminium (Al)	.6	.....
Calcium (Ca)	35	48
Magnesium (Mg)	21	28
Strontium (Sr)	.....	Trace.
Zinc (Zn)	.....	.3
Sodium and potassium (Na+K)	2.9	1.4
Lithium (Li)	.....	Trace
Carbonate radicle (CO_3)	110	142
Borate radicle (B_4O_7)	.....	Trace
Phosphate radicle (PO_4)	Trace.	.....
Sulphate radicle (SO_4)	Trace.	9.4
Chlorine (Cl)	2.8	2.1
Total solids	191	242

[a] Obtained by computation to ionic form; results originally stated in hypothetical combinations.

The following waters are mentioned merely as representative of such as might find a ready market in the cities as table waters. Many others might be included in the list. The numbers at the left correspond with the numbers in Table 22, where the composition of these waters is given.

Possible table waters in the Blue Grass region.

1, 2, and 3. Springs, Anderson County.
4. Riddell well, Boone County.
6. Clark spring, Bourbon County.
12. Furniture Mfg. Co. well, Carroll County.
21. Belmont spring, Fayette County.
29. Wilson well, Fayette County.
32. Harkness well, Fayette County.
38. Madden well, Fayette County.
50. Cox well, Harrison County.
52. Kenney well, Jessamine County.

Table waters can be bottled and shipped to the cities as easily as country milk. By taking advantage of the preference in the cities for pure country waters, the owners of many Blue Grass spring waters could build up a city trade that would yield satisfactory returns.

TABLE 22.—*Analyses of*

[Parts per

No.	County.	Locality.	Owner.	Source.	Analyst.	Date.	Depth of well (feet).
1	Anderson	Tyrone		Spring	Palmer	Oct. 15, 1906	
2	Do	do		do	do	do	
3	Do	do		do	do	do	
4	Boone	Hebron	James Riddell	Well	do	July 31, 1906	30
5	Do	Petersburg	Boone County Distillery.	do	do	Nov. —, 1906	110
6	Bourbon	Paris	W. H. Clark	Spring	do	Sept. 5, 1906	
7	Do	do	Ben Woodford	Well[a b]	do	Nov. —, 1906	50
8	Bracken	Augusta	Electric light plant	do	do	Aug. 26, 1906	96
9	Do	do	Steam laundry	do	do	do	80
10	Do	Brooksville	Cummings Brothers	do	do	do	75
11	Campbell	Newport	Old 76 Distillery	do	R. B. Dole	Apr. 8, 1907	1,250
12	Carroll	Carrollton	Carrollton Furniture Manufacturing Co.	do	Palmer	Sept. 15, 1906	98
13	Do	Sanders	Mrs. Ella Jacobs	Spring[a c]	do	do	
*14	Clark	Kiddville	J. E. Groves	Spring(?)	R. Peter	July —, 1884	
15	Do	Pine Grove	Yunger Jones	Well	Palmer	Nov. —, 1906	90
16	Do	Winchester	Reliance Manufacturing Co.	do[a b]	do	do	55
17	Fayette	Chilesburg	Dr. W. H. Felix	do[a b d]	do	Nov. 24, 1906	75
*18	Do	Donerail	G. F. Bateman	do[e]	A. M. Peter	—— —, 1898	125
19	Do	East of Hickman.	Fayette County Farm	Spring[b]	Palmer	Nov. 16, 1906	
20	Do	Lexington	Ed. Kane	Well[a b]	do	Nov. 9, 1906	76
21	Do	do	August Belmont	Spring	do	do	
22	Do	do	Boice Grogan Lumber Co.	Well	do	Oct. 24, 1906	116
*23	Do	do	Cincinnati Southern Ry.	do	R. Peter	—— —, 1884	80-90
*24	Do	do	do	Well (same).	do	—— —, 1884	153
*25	Do	do	do	do	do	—— —, 1885	800
26	Do	do	W. W. Estill	Well[b]	Palmer	Nov. 22, 1906	40
27	Do	do	R. C. Estill	do[a b d]	do	Nov. 25, 1906	225
28	Do	do	Wm. Fields	Spring[c]	do	Nov. 19, 1906	
29	Do	do	Dr. J. W. Wilson	Well[a b d]	do	Nov. 6, 1906	126
30	Do	do	J. B. Haggin	do[a b]	do	Nov. 25, 1906	198
31	Do	do	H. P. Headley	do	do	Nov. 15, 1906	50
32	Do	do	L. V. Harkness	Spring[b]	do	Nov. 2, 1906	
33	Do	do	J. H. Hisle	Well[d b]	do	Nov. 22, 1906	
34	Do	do	Mrs. Columbia Innes	do[a b]	do	Nov. 18, 1906	225
35	Do	do	Mrs. E. L. Israel	do[d]	do	Nov. 2, 1906	28
36	Do	do	do	do	do	do	28
37	Do	do	Lexington Brewing Co.	do	do	Oct. 23, 1906	150
38	Do	do	J. E. Madden	do[a]	do	Oct. 2, 1906	
39	Do	do	Old Tarr Distillery	Spring	do	Nov. —, 1906	
40	Do	do	Jas. E. Pepper Distillery.	do	do	Nov. 18, 1906	
41	Do	do	Jas. E. Pepper estate	Well	do	Oct. 22, 1906	105
42	Do	do	Wm. Pettit	do	do	Nov. 9, 1906	65
*43	Do	do	Phoenix Hotel Co	do[b]	A. M. Peter	June 26, 1900	
44	Do	do	Mrs. J. Will Sayre	do[b]	Palmer	Nov. —, 1906	168
45	Do	do	W. H. Means	Spring	do	Aug. 23, 1906	
46	Fleming	Flemingsburg	Henderson & O'Bannon ice factory.	Well[a d]	do	Nov. —, 1906	102
*47	Franklin	Frankfort	Old Crow Distillery (W. A. Gaines & Co.).	do[d]	A. Lasche	Aug. 4, 1903	790
48	Do	do	do	do[d]	R. B. Dole	Apr. 8, 1907	790
49	Gallatin	Warsaw	Warsaw furniture factory.	do	Palmer	Aug 10, 1906	90
50	Harrison	Cynthiana	W. M. Cox	do	do	July 26, 1906	50

*Computed from hypothetical combinations.
[a] Trace of the borate radicle (B_4O_7).
[b] Trace of strontium (Sr).
[c] Much hydrogen sulphide (H_2S).
[d] Hydrogen sulphide (H_2S) present.
[e] No hydrogen sulphide (H_2S).
[f] Hydrogen sulphide (H_2S), 4.5 parts.

waters in Blue Grass region.

million.]

Depth to water (feet).	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Lithium (Li).	Bicarbonate Radicle (HCO_3).	Carbonate Radicle (CO_3).	Sulphate Radicle (SO_4).	Chlorine (Cl).	Total solids.	Geologic formation.	No.
.....	9.8	Trace.	0.8	89	5.4	4.3		.....	280	0.0	16	3.5	289	Lexington .	1
.....	6.2	Trace.	1	93	6.1	4.7		.....	283	.....	25	5	296	Highbridge	2
.....	7	Trace.	1	90	7.2	6.9		.....	303	7.4	11	3.5	298	.....do	3
.....	13	Trace.	10	50	3.2	60		.....	274	.0	10	21	318	Glacial.....	4
90	8	Trace.	.6	76	25	9.4		Trace.	294	.0	41	5	330	Alluvium..	5
.....	1.2	Trace.	1.6	32	9.1	27		Trace.	191	.0	9.5	2	193	Lexington .	6
40	10	1.3	.5	238	36	2,990		Trace.	321	21	12	5,415	8,961	.....do	7
50	10	.....	.1	149	17	21		Trace.	451	.0	53	44	493	Alluvium..	8
60	17	.....	.4	101	14	17		Trace.	359	.0	14	26	350	.....do	9
25	6.4	Trace.	.3	76	38	169		Trace.	328	.0	88	250	857	Winchester	10
.....	14	.3	4	360	182	3,700		.....	581	.0	456	6,400	11,680	St. Peter...	11
.....	11	Trace.	.5	90	27	14		Trace.	382	.0	27	19	390	Alluvium..	12
.....	20	Trace.	.8	132	65	1,570		.....	460	.0	349	2,560	5,379	Winchester	13
.....	10	.....	.....	1,108	971	315	22	2.2	.....	243	6,622	139	9,430	Chattanooga.	*14
80	5.8	1	.3	46	20	25		Trace.	242	.0	23	14	259	Lexington .	15
.....	11	2.8	1	271	188	2,813	63	Trace.	374	.0	85	6,700	11,770	Winchester (?).	16
.....	23	1.9	3.9	81	45	421		Trace.	356	.0	21	803	1,583	Lexington (?).	17
.....	.....	.....	.....	1,433	791	10,280	188	3.7	.....	.....	302	20,610	33,667	Lexington .	*18
.....	7.2	Trace.	4.2	91	2.1	7.7		.....	254	.0	19	18	350	.....do	19
.....	4.8	Trace.	.6	60	14	22		Trace.	236	.0	60	6.2	295	.....do	20
.....	6.2	Trace.	.5	96	6.7	6.4		Trace.	292	.0	29	9.2	336	.....do	21
20, 50	6.2	Trace.	2	98	20	12		Trace.	357	.0	40	17	394	.....do	22
.....	36	Trace.	.....	20	4.4	87	5.3	.....	.....	102	41	38	332	.....do	*23
.....	9.4	.....	.....	21	18	92	9.2	.....	.....	124	32	74	379	.....do	*24
.....	4	1.5	.....	47	32	64	19	.....	.....	147	46	91	451	Highbridge	*25
35	7.8	Trace.	.4	79	37	26		.....	369	.0	66	24	424	Lexington .	26
.....	8.6	2.4	.0	114	78	1,705		Trace.	390	.0	11	2,950	5,360	.....do	27
.....	9.4	Trace.	2	58	4.7	6.5		Trace.	170	.0	16	10	219	.....do	28
126	6	.8	1.6	32	20	61		Trace.	259	5.9	28	31	335	.....do	29
.....	8.8	.7	1.7	29	12	340		Trace.	149	.0	12	540	1,035	Lexington (?).	30
.....	6	Trace.	2	54	23	19		Trace.	235	7.7	38	13	284	Lexington .	31
.....	5.8	Trace.	1.5	74	5.1	4		Trace.	236	.0	8.5	4	266	.....do	32
.....	8.4	1.7	.....	44	16	27		Trace.	220	.0	24	30	291	.....do	33
.....	5	1.4	3	95	63	241		Trace.	632	.0	267	160	1,343	Lexington (?).	34
.....	11	4.5	.7	51	34	95		Trace.	376	.0	62	73	577	Lexington .	35
.....	5.4	1	.0	86	9.1	28		Trace.	290	.0	58	14	376	.....do	36
11, 147	7.6	1	.0	96	8.8	17		.....	302	.0	46	5	428	.....do	37
.....	4.6	Trace.	.5	65	20	55		Trace.	312	.0	22	57	482	.....do	38
.....	6	1.1	.0	105	11	18		.....	333	.0	43	23	456	.....do	39
.....	9.4	Trace.	1.3	76	5.7	4.8		.....	242	.0	13	5	255	.....do	40
95	5.4	1	1.4	86	16	7		.....	297	.0	42	8.5	343	.....do	41
65	5.4	Trace.	1.3	49	20	6.8		Trace.	208	.0	39	7.1	243	.....do	42
.....	8	2.8	.....	92	34	67		.....	.....	166	95	104	640	.....do	*43
48, 168	3.8	1	1.6	86	6.7	4.4		Trace.	292	.0	4.6	6.7	315	.....do	44
.....	22	4.2	1.6	41	20	32		Trace.	236	.0	41	18	361	Ohio.....	45
65	7.8	1	.2	43	24	263		Trace.	349	.0	76	284	910	Maysville..	46
.....	.....	1.1	.....	57	28	410	.....	.....	65	.....	195	620	1,610	St. Peter(?)	*47
.....	12	.1	.....	54	26	501		.....	305	.0	204	640	1,596	.....do	48
80	13	Trace.	.6	82	19	19		Trace.	345	12	16	5	336	Alluvium..	49
45	12	Trace.	3	114	28	23		.....	351	.0	76	64	540	Lexington .	50

TABLE 22.—*Analyses of water*

No.	County.	Locality.	Owner.	Source.	Analyst.	Date.	Depth of well (feet).
51	Harrison	Leesburg	Jas. Crombie	Well	Palmer	July 26, 1906	76
52	Jessamine	Nicholasville	C. A. Kenney	do	do	Oct. 13, 1906	75
53	Kenton	Covington	Cincinnati Ice Co	do.[a]	do	July 11, 1906	200
54	Do	Independence	Dr. F. J. Metcalf	do	do	July 13, 1906	45
*55	Madison	Clear Creek Station.	John R. Proctor	do	R. Peter	—— —, 1880	126
*56	Do	Paint Lick	J. H. Spilman	do	do	—— —, 1858	18
57	Mason	Maysville	R. A. Carr	do	Palmer	Aug. 27, 1906	108
58	Do	Sardis	Town	do.[b c]	do	Oct. —, 1906	300
59	Nicholas	Carlisle	Carlisle Milling Co	do.[c]	do	Aug. 13, 1906	155
60	Do	do	City	do	do	do	35
61	Owen	Owenton	Thomas & Ruth	do.[c]	do	Sept. 13, 1906	17
62	Pendleton	Butler	Doctor Huddleston	do	do	Sept. 7, 1906	30
63	Do	Falmouth	H. W. Faber	do	do	July 21, 1906	39
64	Do	Morgan	S. F. Fornash	do	do	July 24, 1906	37
65	Robertson	Mount Olivet	John Zoller	do	do	Aug. 10, 1906	103
66	Scott	Georgetown	Judge James Askew	do	do	Oct. 4, 1906	70
67	Do	Sadieville	City	do.[b]	do	Oct. 1, 1906	188
68	Do	Stamping Ground.	J. L. Turnbull	Spring[c]	do	Oct. —, 1906	.....
69	Shelby	Shelbyville	T. J. Ramsay	do	do	Sept. 18, 1906	.....
70	Trimble	Bedford	Mrs. Mary J. Bell	Well	do	do	22
71	Do	Milton	Richwood Distillery	do	do	Nov. —, 1906	96
72	Woodford	Mortonsville	E. Boston	do.[c]	do	Oct. 10, 1906	51
73	Do	Nonesuch	B. Bond	do.[a]	do	do	40
74	Do	Versailles	Lucas Brodhead	do	do	Oct. 2, 1906	63

* Computed from hypothetical combinations.
[a] Hydrogen sulphide (H_2S) present.
[b] Trace of the borate radicle (B_4O_7
[c] Trace of strontium (Sr).

in Blue Grass region—Continued.

Depth to water (feet).	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Lithium (Li).	Bicarbonate Radicle (HCO_3).	Carbonate Radicle (CO_3).	Sulphate Radicle (SO_4).	Chlorine (Cl).	Total solids.	Geologic formation.	No.
68	17	5	2.1	80	45	14		Trace.	361	.0	104	14	479	Lexington.	51
62	6.8	Trace.	1.1	102	19	30		Trace.	315	.0	82	38	469	.....do.....	52
65	9.6	Trace.	.8	130	16	16		.....	415	.0	49	25	479	Alluvium..	53
16	13	Trace.	4.8	110	34	35		Trace.	185	.0	184	105	669	Maysville..	54
.....	6	.....	....	72	14	61	56	.....	262	.0	38	89	466	Upper Cincinnatian.	*55
.....	44	Trace.	....	22	4.2	311	33	.....	363	.0	97	276	966	Lower Silurian.	*56
.....	14	Trace.	1.4	116	17	63		Trace.	398	.0	99	50	662	Alluvium..	57
.....	9.2	3.8	.0	160	89	3,260		Trace.	206	14	54	6,800	12,106	Winchester (?)	58
150	5	9.8	3.7	107	21	765		Trace.	454	.0	3.3	1,800	3,222	Winchester	59
.....	10	Trace.	2.1	184	36	29		.....	377	.0	176	130	875	.....do.....	60
.....	17	Trace.	2.2	200	24	127		Trace.	478	.0	105	264	1,202	Maysville..	61
.....	9.8	Trace.	2	71	2.8	26		.....	216	.0	35	23	296	Alluvium..	62
.....	15	Trace.	3.4	122	41	39		.....	490	.0	30	88	748		63
.....	15	Trace.	12	121	35	37		.....	430	.0	75	73	703	Maysville..	64
80	11	Trace.	.8	32	17	204		.....	539	.0	136	9.6	720		65
70	8	Trace.	1.5	73	14	6.5		.....	246	.0	39	10	373	Lexington.	66
.....	4.8	.5	2.5	48	30	280		Trace.	328	29	8.9	396	1,050	Winchester	67
.....	8.8	Trace.	1.6	69	4.4	3.8		Trace.	221	.0	9	4.7	222	Lexington.	68
.....	16	Trace.	.7	264	31	398		Trace.	600	.0	28	802	1,914	Maysville..	69
.....	17	Trace.	.4	91	20	37		.....	337	.0	11	71	465	Panola.....	70
±65	6	Trace.	.8	76	18	6.2		Trace.	294	.0	22	9.3	311	Alluvium..	71
51	7.8	Trace.	.7	59	22	54		Trace.	251	.0	87	40	439	Lexington.	72
.....	6.2	1	....	42	16	66		Trace.	248	.0	26	60	351	Highbridge	73
50	6.4	Trace.	1.2	74	8.6	7.7		.....	242	.0	28	7.7	258	Lexington.	74

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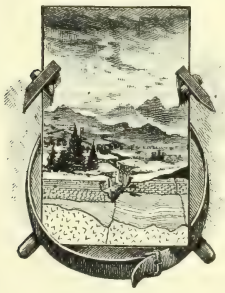
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 234

PAPERS ON THE CONSERVATION OF WATER RESOURCES

REPRINTED FROM REPORT OF THE NATIONAL CONSERVATION COMMISSION, FEBRUARY, 1909



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PAPERS ON THE CONSERVATION OF WATER RESOURCES.

INTRODUCTION.

This volume is a reprint of selected papers on the conservation of water resources, written by members of the United States Geological Survey in response to executive order, for the report of the National Conservation Commission (S. Doc. 676, 60th Cong., 2d sess.). Nearly all the information from which the papers are compiled had previously been collected by the Survey in the performance of its regular duties. The remainder has been taken from the records of other federal bureaus. The papers, therefore, constitute a summation of certain official work which has been in progress for more than twenty years and whose results eventually must have been published in the regular series of water-supply papers had they not been diverted to become a part of the larger work on conservation. The printing of the conservation report has furnished an opportunity to present these reprints in convenient form and, as the demand for the larger report will greatly exceed the edition authorized, this segregation of the papers relating to water will prove useful.

MAP OF
UNITED STATES
SHOWING
MEAN ANNUAL PRECIPITATION
PREPARED BY
HENRY GANNETT
MAINLY FROM DATA OF U. S. WEATHER BUREAU

DISTRIBUTION OF RAINFALL.

By Henry Gannett.

The ultimate source of our water supply is rainfall, the chief source of which is evaporation from the Pacific Ocean, while secondary sources are the Gulf of Mexico and the Atlantic Ocean. Brought from the Pacific by the westerly winds of the north temperate zone, the moisture in the air is carried eastwardly nearly across the continent in diminishing quantities, varying at different times of the year. The supply in the atmosphere is reenforced in the Mississippi Valley from the Gulf of Mexico, whence it is drawn inland by southerly and southwesterly winds; and again east of the Appalachian Mountains it is reenforced from the Atlantic Ocean, from which it is drawn by easterly winds accompanying cyclonic disturbances.

The areal distribution of the rainfall is in general terms as follows: The precipitation is very heavy upon the north Pacific coast, where at several points in the States of Washington and Oregon it exceeds 100 inches annually, but diminishes southward so that at San Diego, Cal., the rainfall is very light and desert conditions prevail. Inland, back of the Coast Ranges, the northern part of the great depression separating these mountains from the Cascades and the Sierra Nevada is well watered. The amount of rainfall diminishes southward, so that in the southern part of the depression, which is occupied by the San Joaquin Valley, precipitation is scanty and arid conditions exist. The high mountains of the Cascade Range and of the Sierra Nevada are copiously watered, but east of them, in the valleys and low plateaus and on the great plains as far east as the one hundredth meridian, the rainfall is very light. The mountains of this (the Rocky Mountain) region, however, enjoy a more copious rainfall than the valleys, the amount differing with the altitude and latitude, the more northerly and higher ranges receiving the greater amount.

Continuing eastward, the small supply of moisture still remaining from that brought from the Pacific Ocean is augmented by a generous contribution from the Gulf of Mexico, and the rainfall increases. Upon much of the Gulf coast it exceeds 60 inches annually, but it diminishes northward, until in the neighborhood of the

Great Lakes the precipitation does not exceed 30 inches yearly. The Appalachian Mountains are abundantly watered, and the Atlantic plain receives everywhere a sufficiency for agricultural purposes, derived largely from the Atlantic Ocean.

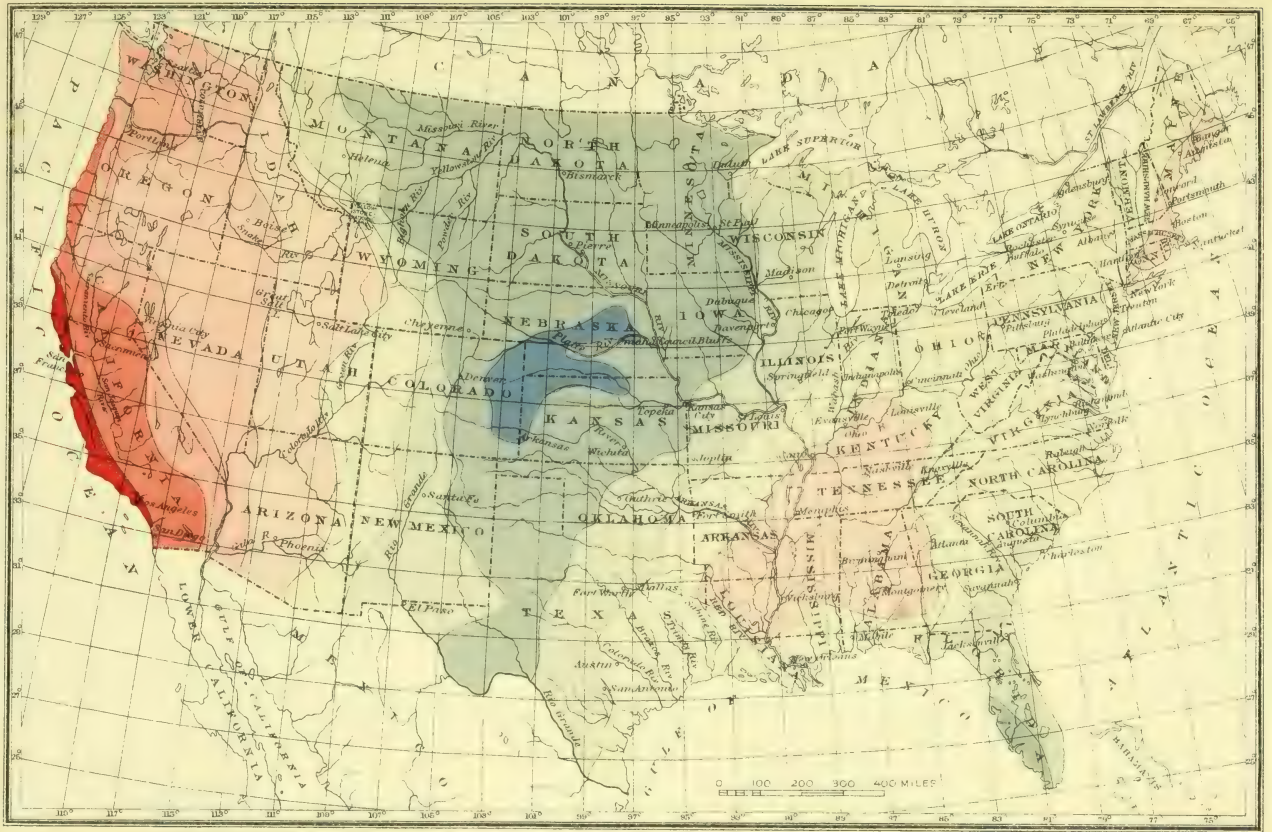
The causes of these great differences in amounts of precipitation in the various parts of the country are simply explained. All air holds a certain amount of moisture, ranging from the amount sufficient to saturate it to a very small proportion of that quantity. The point of saturation is much higher in warm air than in cold air; i. e., warm air can hold a much larger quantity of moisture than can cold air. Whenever air is cooled below the point of saturation, rain falls, and it can only fall when thus chilled. There are several ways in which air currents may be cooled; the current may be forced upward, as when it climbs the slope of a mountain range; it may be cooled by intermingling with colder air currents; and again, by coming in contact with a cold land.

The sea receives heat slowly and parts with it slowly; the land, on the contrary, is rapidly heated and parts with its heat as quickly. It results from these conditions that the ocean has a fairly uniform temperature the year around, while the land is much colder in winter than in summer.

Now, let us apply these principles to the United States. The prevailing winds in the Temperate Zone are from the west. These winds come off the Pacific laden with moisture and having the temperature of the ocean. If they encounter land having a lower temperature they are chilled below the point of saturation and some of the moisture is deposited in the form of rain or snow. If, on the other hand, the land is warmer than the air, the currents pass over it without any reduction in temperature and with little or no loss of moisture.

During the winter the north Pacific coast is colder than the sea, and hence the copious precipitation which it enjoys at that season of the year. In the summer the conditions are reversed, and the air currents, although containing at least as much moisture as in cold weather, pass over the land with comparatively little loss from precipitation. Southward, down the coast, the land is progressively warmer in winter, and consequently receives less rain, while in southern California there is little rain even in winter, except upon the mountains. Although the atmosphere at Los Angeles contains more moisture than does that at Washington, D. C., rain seldom falls in the former locality, as there is nothing to cool the air currents.

Thus it is that the Pacific coast has well-defined wet and dry seasons corresponding to winter and summer in other parts of the country. In winter the country drains the air currents of their moisture and they pass eastward as dry winds, while in summer these currents carry most of their moisture over the mountains and precipitate it upon the Rocky Mountains farther to the east and upon



PERCENTAGE OF ANNUAL PRECIPITATION RECEIVED IN THE SIX WARMER MONTHS, APRIL TO SEPTEMBER, INCLUSIVE

the great plains. Hence, it is that in these two regions the greater part of the year's rainfall occurs in the warmer half of the year.

Going eastward into the Mississippi Valley the moist air currents, drawn northward from the Gulf of Mexico by southerly winds, are carried progressively into more northerly and colder climates, and part of their moisture is deposited in a similar manner.

The Weather Bureau has furnished the Commission with data upon precipitation from about 4,000 stations within the limits of the United States proper. These data consist of records of the normal yearly and monthly rainfall, and the study which has been made of them is very illuminating.

In preparing the rainfall map (Pl. I), the data from all these stations were platted upon a large-scale map of the United States, and in the plains and level country generally isohyetal lines were sketched at intervals of 10 inches of rainfall in accordance with these data. In the mountain regions, however, but little weight was given to the rainfall data, inasmuch as the stations are generally situated in the canyons rather than on the ridges, and hence do not represent well the rainfall of the region, but in such country consideration was given to the relief of the land, its mountains, etc., and to the character of its vegetation; it is known, for instance, that the lower limit of yellow pine timber is not far from the isohyetal line of 20 inches. The areas between these isohyetal lines were measured by planimeter, and the average rainfall of each such area was assumed to be the mean of the two isohyetal lines limiting it. The areas were then multiplied by their average rainfall, the products summed up, and the total divided by the total area of the country. In this way the figure, 29.4 inches, was obtained as the mean average rainfall of the United States.

Another use has been made of these data. The percentage of the annual rainfall which was received during the six warmer months was computed for each station, and the results platted (Pl. II), thus showing the preponderance of summer or winter rainfall throughout the country. Over most of the area the greater part of the rain occurs in the warmer season, but upon the Pacific coast and in the Rocky Mountains as far east as western Montana, eastern Idaho, eastern Utah, and Arizona the bulk of the precipitation comes in the colder season. The highest proportion, three-fourths to four-fifths of that of the year, is on or near the Pacific coast, and the proportion diminishes eastward. Again, in an area adjacent to the Gulf of Mexico, winter rainfall preponderates slightly. The highest proportional summer rainfall is on the plains east of the Rocky Mountains, where it ranges from three-fourths to four-fifths of that of the year. In the Mississippi Valley and on the Atlantic plain the proportion which falls in the warmer season is but little more than half of the annual precipitation.

FLOODS.

By M. O. Leighton.

INCREASE.

A broad and comprehensive review of river-discharge records in the United States indicates unmistakably that floods are increasing. It is true that the opposite tendency may be shown on some rivers, while the records on others may indicate little or no change; but, taken as a whole, the rivers that reveal more intense flood tendencies so thoroughly dominate the situation that the conclusion above expressed must be inevitable.

It will be well to consider at the outset just what index may be used to determine the trend of flood tendencies. It is common in inquiries of this character to select and compare the highest stages attained in the several years of record, and because, perchance, higher floods may be shown in early years, many really competent persons have believed themselves forced to the conclusion that there is no increase in flood tendency. The actual height attained by the maximum flood each year is, however, a matter of small consequence in such considerations. A little reflection will show how this must be true. The precipitation, which is the ultimate cause of floods, takes three courses, only two of which are really important in the present discussion, namely, the course along the surface of the ground directly into watercourses, and that into the ground by percolation, with subsequent discharge into the rivers by seepage. In general terms it may be stated that the water which causes floods is that proportion of the precipitation which the earth does not absorb and which, therefore, must flow along the earth's surface. Now it is apparent that when precipitation becomes so intense and long continued that it practically saturates the ground the rain that falls thereafter must take the direct route and floods must necessarily arise. Therefore the height of great floods is fixed primarily by the intensity of precipitation and, as the amount of rain varies from year to year, now bountiful and again scanty in what seem to be fairly uniform cycles of years, the observation of an especially high flood during an early year compared with that of a much lower one during a recent year can give no index to flood tendency in any river. The real index is of more fundamental origin than the mere occurrence of high floods.

When the question "Are floods increasing?" is asked, the considerations involved are not those of height but those of duration and frequency. In other words, the question means, Are floods of more frequent occurrence and are there more days of flood than formerly?

Reverting for the moment to the discussion in the foregoing paragraphs, it is plain that floods will occur more frequently in response to a given rate of precipitation, if there are in the drainage area influences that either inhibit or prevent the ready absorption of the rain by the ground, than they would if absorption were ideal. Such ideal condition assures complete absorption of all precipitation. A rain of a given depth in a unit's time—say 2 inches in one day—would surely produce a flood in a drainage area which was nonabsorbent. On the other hand, the same amount of rain would not change the river stage if the conditions enhancing absorption on the drainage area were ideal. Between these two extremes there are wide and varying conditions which tend to increase or to diminish the resultant floods from a given rainfall. In other words, the question "Are floods increasing?" means, essentially, Are the conditions of the surface of the ground in the river basins so changing that they render the ground less absorbent? If this be the case, it is clear that a much larger proportion of the precipitation would run directly off into the rivers than that which was so conducted at an earlier period.

There are five classes of agencies or conditions affecting the flow of streams. The first is climate, under which are comprised rainfall, evaporation, temperature, wind, and humidity. Although these are exceedingly variable from day to day and from season to season, the observations that have been recorded indicate that a period of years embraces all conditions, so that the mean of them may be considered fairly constant. There is very little evidence, except in special areas, that reveals any progressive and permanent change in climatic conditions. The second agency is topography, and the third geology, both of which may, for present purposes, be considered absolutely stable. The fourth is surface vegetation, which includes forest cover and cultivated land. This is subject to progressive change, according to the demands, conveniences, and usages of society. The fifth consists of artificial agencies, such as storage, reservoirs, and drainage, which produce rapid and marked effects on river discharge.

Therefore, the consideration of river discharge and especially of floods involves the appraisal of the effects of climate, vegetation, and artificial agencies. The other two agencies, being constant, may be left out of consideration. It is necessary to take account of these conditions in connection with all studies of progressive flood trend. This emphasizes the futility of many studies that have heretofore been made, in which not only have the extreme flood heights

been the basis of determination, but there has been a total lack of consideration of climatic conditions, especially that of rainfall. A river, for example, may show a progressive decrease in flood frequency during a period of years. If that were taken alone it would indicate a decreasing flood trend; whereas, if the rainfall be compared progressively in the same manner, it might readily be shown that the flood trend was increasing rather than diminishing, because the precipitation was decreasing faster than the flood frequency.

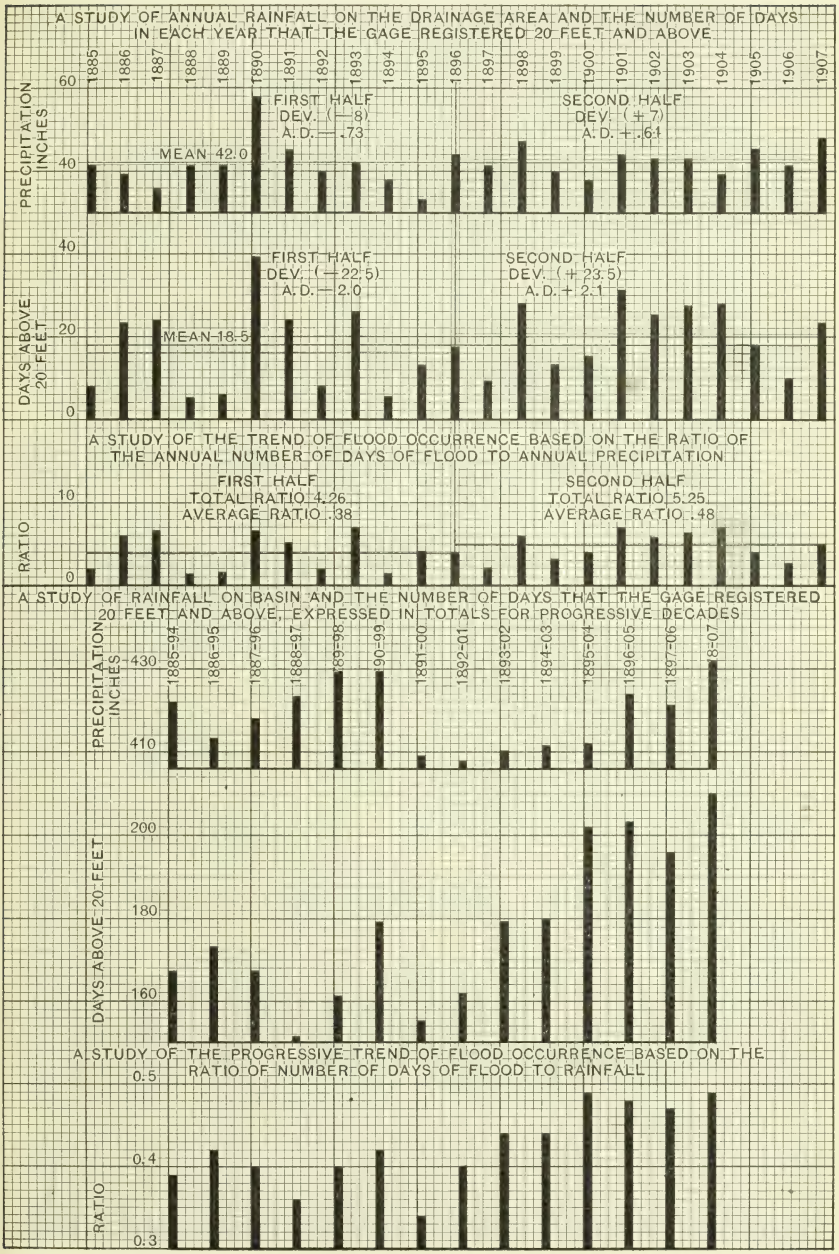
The above considerations have been kept in mind in the study of flood frequency here presented. The accompanying diagrams (pp. 13 to 20) are the result of appropriate studies made of flood occurrence on rivers on which gages have been maintained for a long period, the longest, in fact, of which there are available and useful records in this country. Examination shows conclusively the increasing trend of flood occurrence and the cause thereof comes now properly into question.

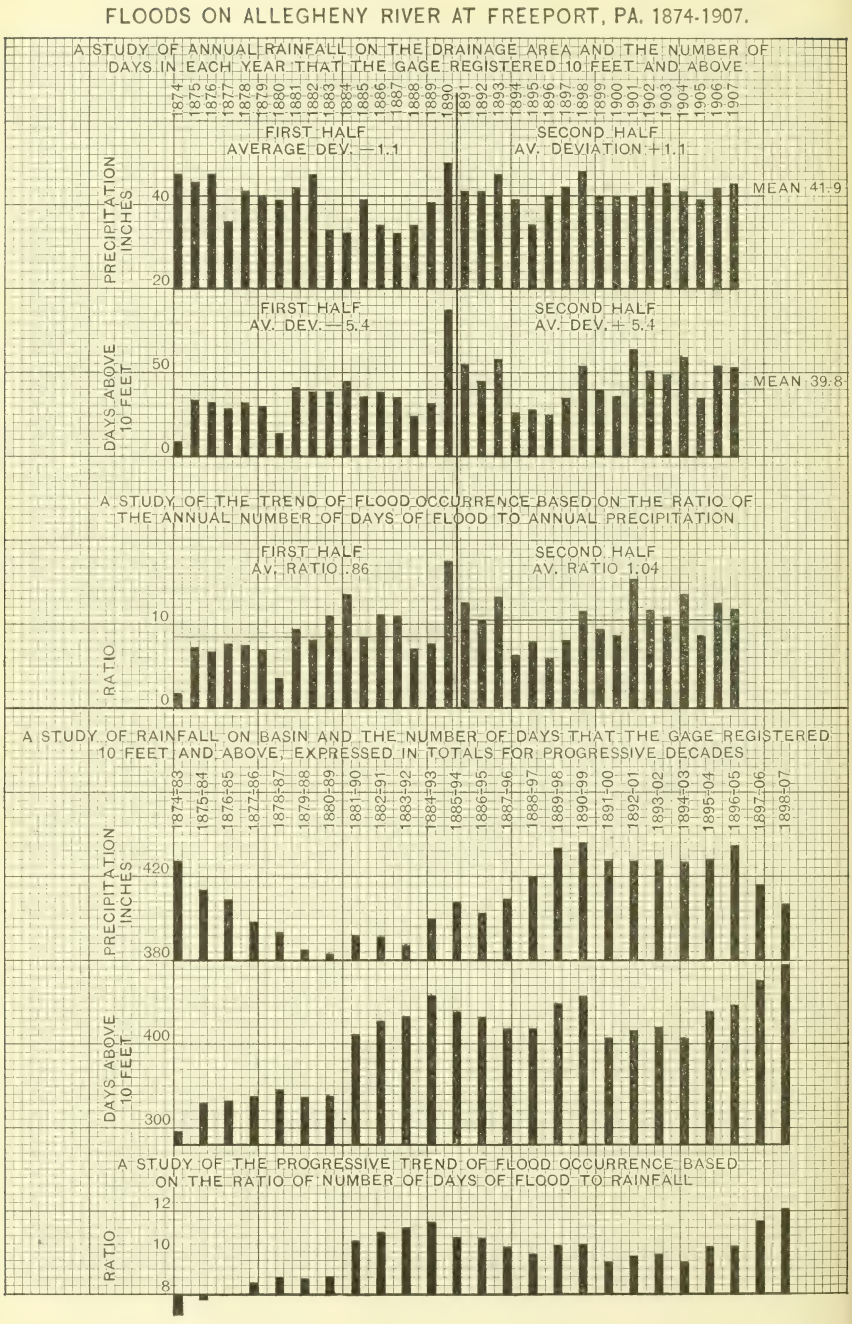
As already stated, the rainfall, which is by far the most important of the climatic conditions, has been accounted for in these diagrams, and we have, therefore, remaining only the condition of the ground surfaces in the drainage areas and artificial agencies. For each of these rivers artificial agencies may be eliminated. Our general knowledge of conditions on the drainage areas gives assurance that there has been no reservoir installation of extent sufficient to modify in the slightest degree the normal conditions of flood discharge. This is also true with respect to artificial drainage.

Therefore we come down to the condition of the land surface, or, as above expressed, conditions of vegetation. We are aware that on all of these drainage areas there has been progressive cutting of timber and building of roads. The latter improvements, however, have not been of sufficient extent to modify in any appreciable degree the discharge. A computation of the actual road areas, including the paved streets, etc., will show conclusively that, in comparison with the total area under consideration, they are insignificant. The conditions of cultivated fields undoubtedly have a marked influence in modifying the rate of river discharge, and it is certain that some of the effects in these areas are due to this cause. The cultivation of fields has, however, improved markedly in recent years. The farmer has learned to a considerable degree that it is more profitable for him to cultivate his inclined fields by contour or terrace cultivation, and a cursory view of the areas represented in the accompanying diagrams will show that to a very large extent improved methods of cultivation have been put into effect.

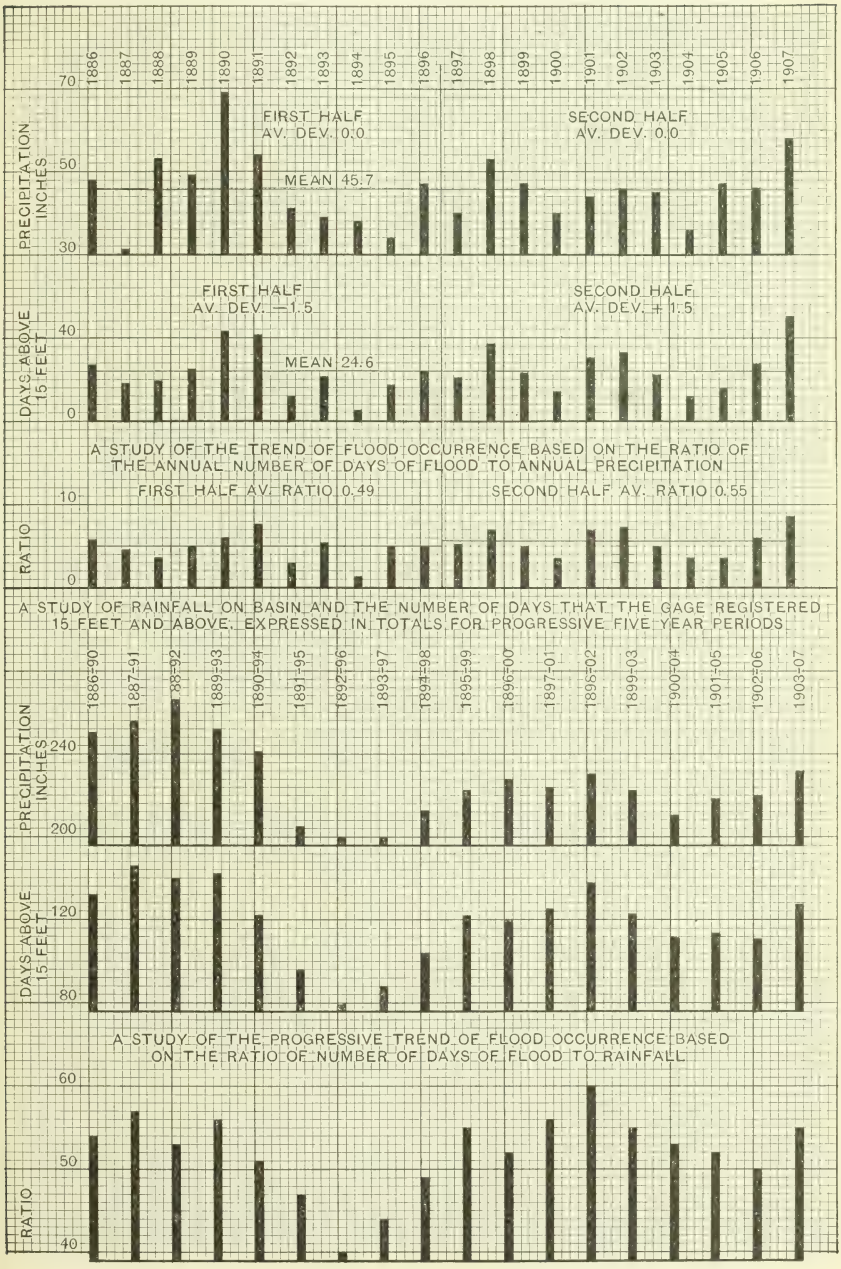
Altogether, when the physical conditions on the drainage areas are summed up, the one great change that has been produced in the vegetative conditions is the reduction of forest area. On some of these

FLOODS ON OHIO RIVER AT WHEELING, W. VA. 1885-1907

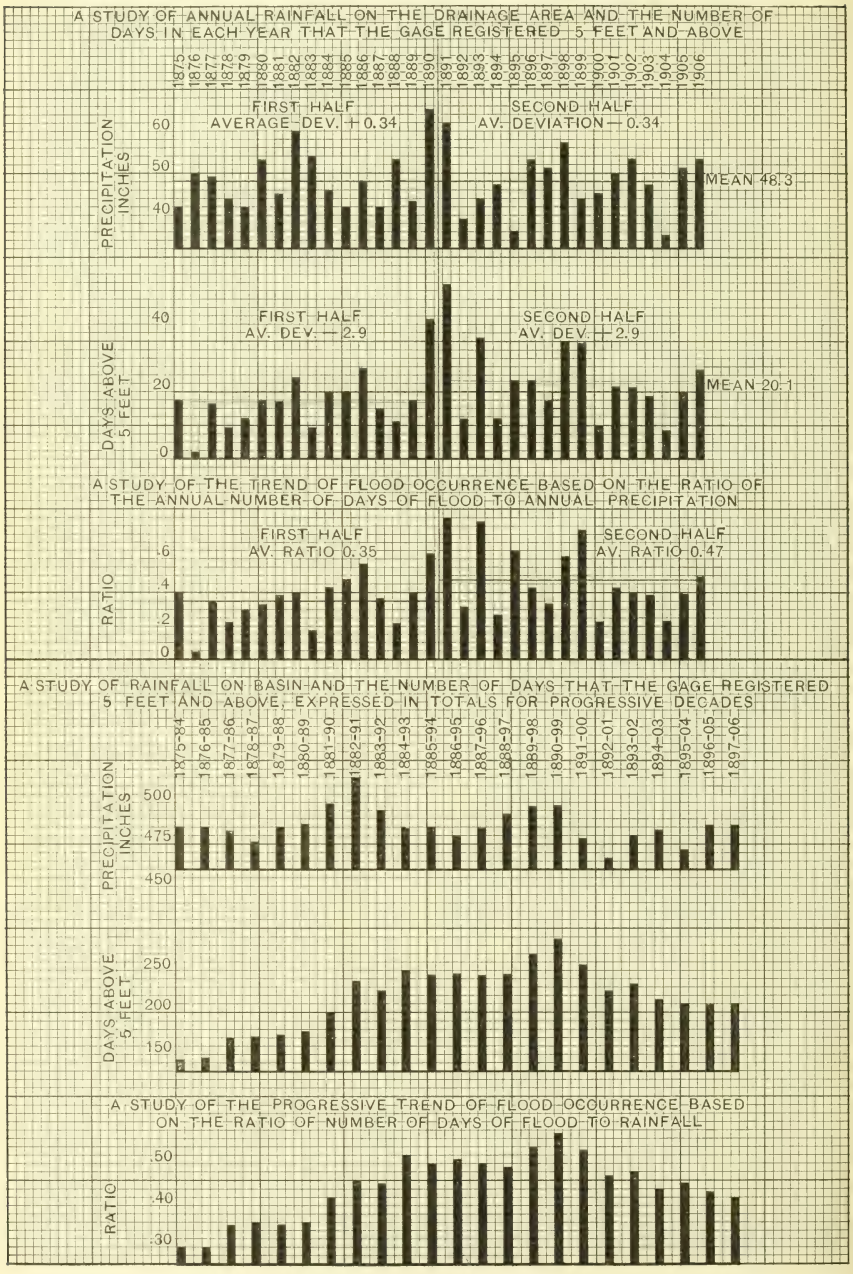



FLOODS ON ALLEGHENY RIVER AT FREEPORT, PA. 1874-1907.
A STUDY OF ANNUAL RAINFALL ON THE DRAINAGE AREA AND THE NUMBER OF DAYS IN EACH YEAR THAT THE GAGE REGISTERED 10 FEET AND ABOVE
1874 1875 1876 1877 1878 1879 1880 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900 1901 1902 1903 1904 1905 1906 1907
FIRST HALF
AVERAGE DEV. —1.1
SECOND HALF
AV. DEVIATION +1.1
PRECIPITATION INCHES
40
20
MEAN 41.9
FIRST HALF
AV. DEV. —5.4
SECOND HALF
AV. DEV. + 5.4
DAYS ABOVE 10 FEET
50
0
MEAN 39.8
A STUDY OF THE TREND OF FLOOD OCCURRENCE BASED ON THE RATIO OF THE ANNUAL NUMBER OF DAYS OF FLOOD TO ANNUAL PRECIPITATION
FIRST HALF
Av. RATIO .86
SECOND HALF
AV. RATIO 1.04
RATIO
10
0
A STUDY OF RAINFALL ON BASIN AND THE NUMBER OF DAYS THAT THE GAGE REGISTERED 10 FEET AND ABOVE, EXPRESSED IN TOTALS FOR PROGRESSIVE DECADES
1874-83 1875-84 1876-85 1877-86 1878-87 1879-88 1880-89 1881-90 1882-91 1883-92 1884-93 1885-94 1886-95 1887-96 1888-97 1889-98 1890-99 1891-00 1892-01 1893-02 1894-03 1895-04 1896-05 1897-06 1898-07
PRECIPITATION INCHES
420
380
DAYS ABOVE 10 FEET
400
300
A STUDY OF THE PROGRESSIVE TREND OF FLOOD OCCURRENCE BASED ON THE RATIO OF NUMBER OF DAYS OF FLOOD TO RAINFALL
RATIO
12
10
8

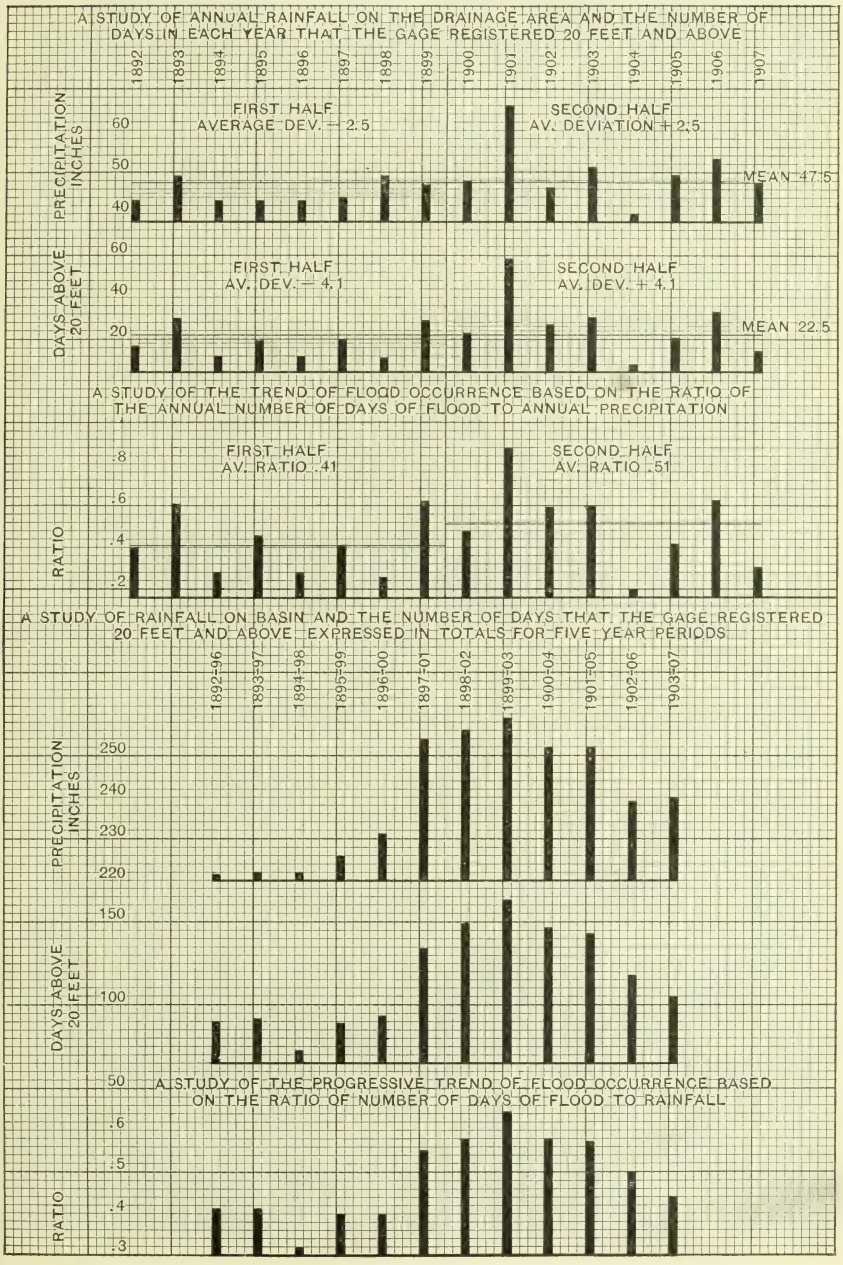
FLOODS ON MONONGAHELA RIVER AT LOCK NO. 4, PA. 1886-1907.



FLOODS ON YOUGHIOGHENY RIVER AT CONFLUENCE, PA. 1875–1906.


A STUDY OF ANNUAL RAINFALL ON THE DRAINAGE AREA AND THE NUMBER OF DAYS IN EACH YEAR THAT THE GAGE REGISTERED 5 FEET AND ABOVE
1875 1876 1877 1878 1879 1880 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900 1901 1902 1903 1904 1905 1906
PRECIPITATION INCHES
60
50
40
FIRST HALF
AVERAGE DEV. + 0.34
SECOND HALF
AV. DEVIATION — 0.34
MEAN 48.3
DAYS ABOVE 5 FEET
40
20
0
FIRST HALF
AV. DEV. — 2.9
SECOND HALF
AV. DEV. — 2.9
MEAN 20.1
A STUDY OF THE TREND OF FLOOD OCCURRENCE BASED ON THE RATIO OF THE ANNUAL NUMBER OF DAYS OF FLOOD TO ANNUAL PRECIPITATION
RATIO
.6
.4
.2
0
FIRST HALF
AV. RATIO 0.35
SECOND HALF
AV. RATIO 0.47
A STUDY OF RAINFALL ON BASIN AND THE NUMBER OF DAYS THAT THE GAGE REGISTERED 5 FEET AND ABOVE, EXPRESSED IN TOTALS FOR PROGRESSIVE DECADES
1875-84 1876-85 1877-86 1878-87 1879-88 1880-89 1881-90 1882-91 1883-92 1884-93 1885-94 1886-95 1887-96 1888-97 1889-98 1890-99 1891-00 1892-01 1893-02 1894-03 1895-04 1896-05 1897-06
PRECIPITATION INCHES
500
475
450
DAYS ABOVE 5 FEET
250
200
150
A STUDY OF THE PROGRESSIVE TREND OF FLOOD OCCURRENCE BASED ON THE RATIO OF NUMBER OF DAYS OF FLOOD TO RAINFALL
RATIO
.50
.40
.30

FLOODS ON WATEREE RIVER AT CAMDEN, S. C. 1892-1907.



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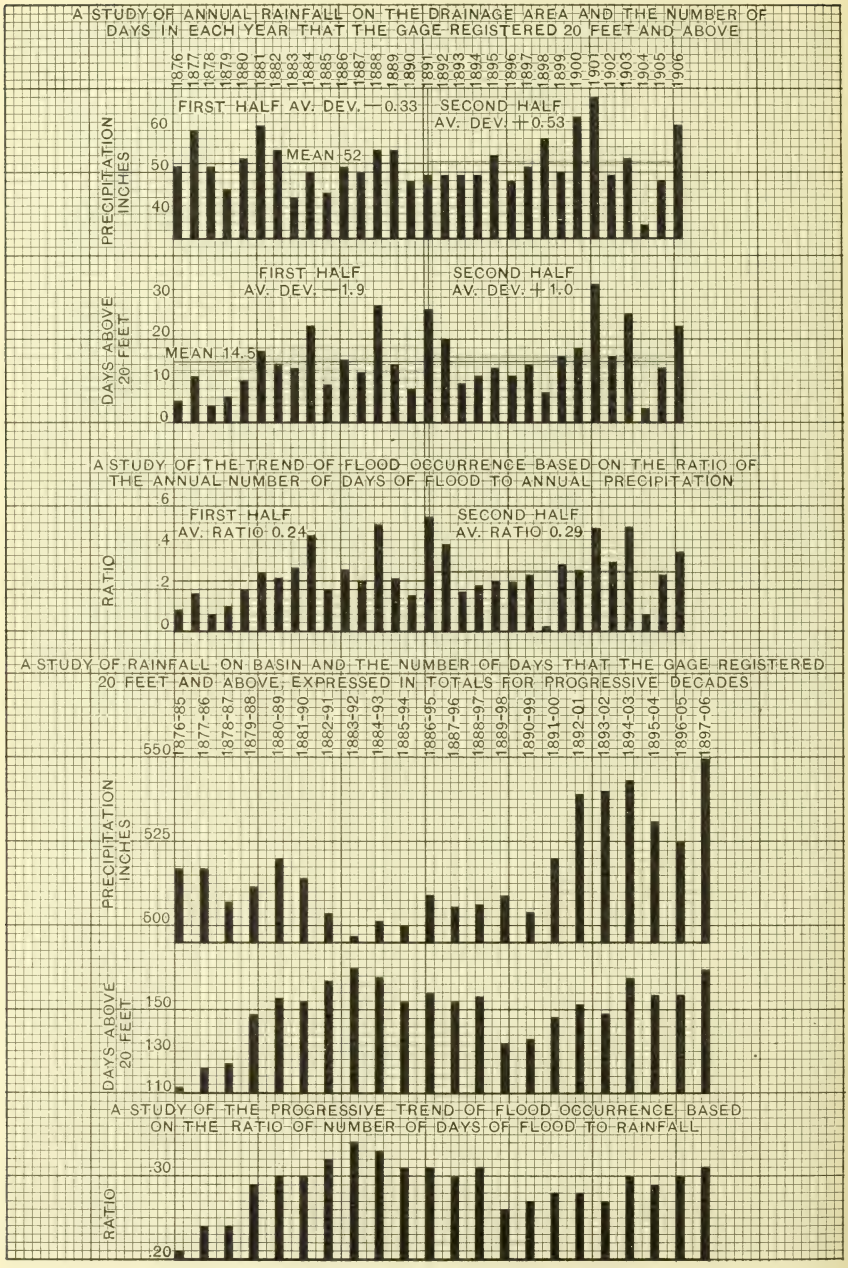
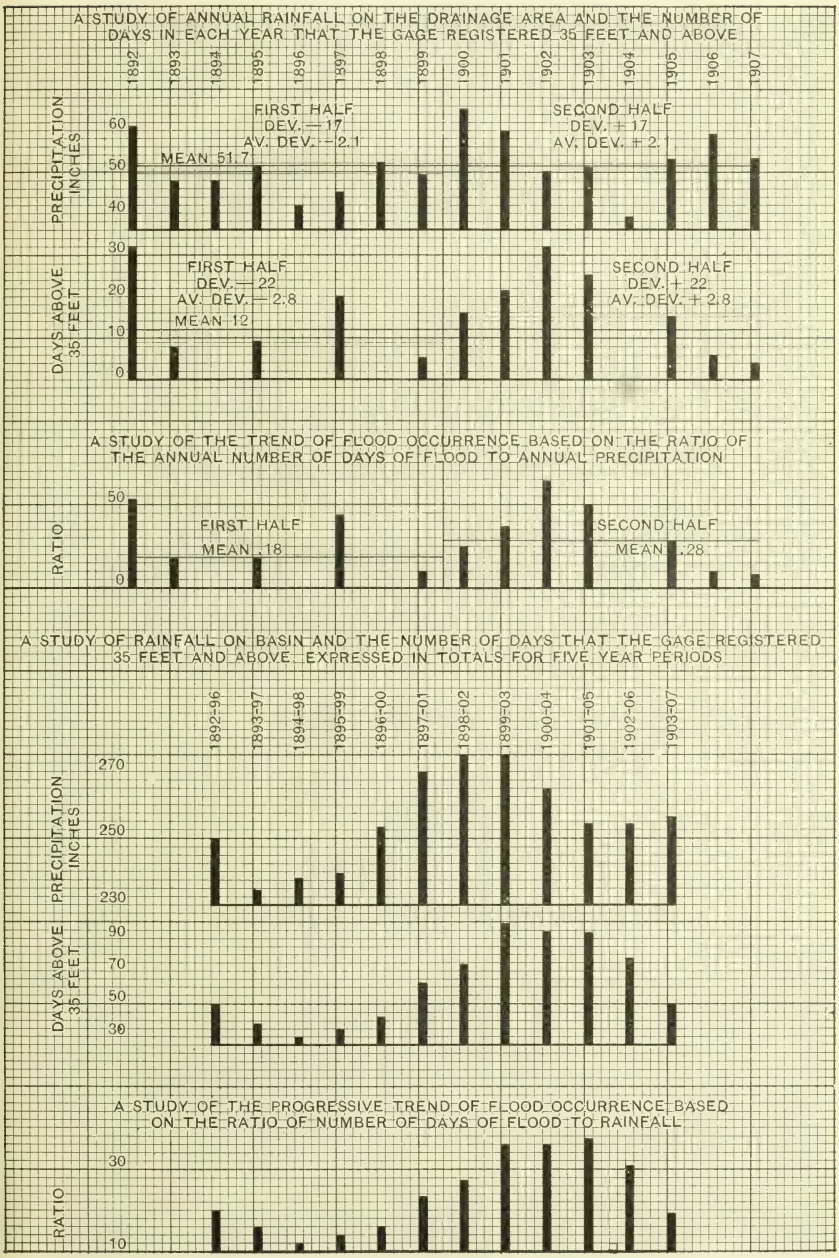
FLOODS ON SAVANNAH RIVER AT AUGUSTA, GA. 1876–1906.


A STUDY OF ANNUAL RAINFALL ON THE DRAINAGE AREA AND THE NUMBER OF DAYS IN EACH YEAR THAT THE GAGE REGISTERED 20 FEET AND ABOVE
1876 1877 1878 1879 1880 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900 1901 1902 1903 1904 1905 1906
PRECIPITATION INCHES
60
50
40
FIRST HALF AV. DEV. —0.33
SECOND HALF AV. DEV. +0.53
MEAN 52
DAYS ABOVE 20 FEET
30
20
10
0
FIRST HALF AV. DEV. —1.9
SECOND HALF AV. DEV. +1.0
MEAN 14.5
A STUDY OF THE TREND OF FLOOD OCCURRENCE BASED ON THE RATIO OF THE ANNUAL NUMBER OF DAYS OF FLOOD TO ANNUAL PRECIPITATION
RATIO
6
4
2
0
FIRST HALF AV. RATIO 0.24
SECOND HALF AV. RATIO 0.29
A STUDY OF RAINFALL ON BASIN AND THE NUMBER OF DAYS THAT THE GAGE REGISTERED 20 FEET AND ABOVE, EXPRESSED IN TOTALS FOR PROGRESSIVE DECADES
1876-85 1877-86 1878-87 1879-88 1880-89 1881-90 1882-91 1883-92 1884-93 1885-94 1886-95 1887-96 1888-97 1889-98 1890-99 1891-00 1892-01 1893-02 1894-03 1895-04 1896-05 1897-06
PRECIPITATION INCHES
550
525
500
DAYS ABOVE 20 FEET
150
130
110
A STUDY OF THE PROGRESSIVE TREND OF FLOOD OCCURRENCE BASED ON THE RATIO OF NUMBER OF DAYS OF FLOOD TO RAINFALL
RATIO
.30
.20

FLOODS ON ALABAMA RIVER AT SELMA, ALA. 1892-1907.



FLOODS ON CONNECTICUT RIVER AT HOLYOKE, MASS. 1874-1907.

A STUDY OF ANNUAL RAINFALL ON THE DRAINAGE AREA AND THE NUMBER OF DAYS IN EACH YEAR THAT THE GAGE REGISTERED 50 FEET AND ABOVE
1874 1875 1876 1877 1878 1879 1880 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900 1901 1902 1903 1904 1905 1906 1907
FIRST HALF
AVERAGE DEVIATION ± .09
SECOND HALF
AV. DEV. = .09
RAINFALL INCHES
50
40
30
20
MEAN 41.45
FIRST HALF
AV. DEV. = .025
SECOND HALF
AV. DEV. ± .025
DAYS ABOVE 50 FEET
75
50
25
MEAN 37.5
A STUDY OF THE TREND OF FLOOD OCCURRENCE BASED ON THE RATIO OF THE ANNUAL NUMBER OF DAYS OF FLOOD TO ANNUAL RAINFALL
FIRST HALF
AVERAGE RATIO .86
SECOND HALF
AVERAGE RATIO .95
RATIO
1.50
1.00
.50
A STUDY OF RAINFALL ON BASIN AND THE NUMBER OF DAYS THAT THE GAGE REGISTERED 50 FEET AND ABOVE, EXPRESSED IN TOTALS FOR PROGRESSIVE DECADES
1874-83 1875-84 1876-85 1877-86 1878-87 1879-88 1880-89 1881-90 1882-91 1883-92 93 1885-94 1886-95 1887-96 1888-97 1889-98 1890-99 1891-00 1892-01 1893-02 1894-03 1895-04 1896-05 1897-06 1898-07
RAINFALL INCHES
450
425
400
DAYS ABOVE 50 FEET
400
300
A STUDY OF THE PROGRESSIVE TREND OF FLOOD OCCURRENCE BASED ON THE RATIO OF NUMBER OF DAYS OF FLOOD TO PRECIPITATION
RATIO
1.00
.90
80

drainage areas it has occurred by slow progression and on others more rapidly. It is certain that in some areas this forest cutting has caused barren conditions, because the land was of such a character that, after it was relieved of forest protection, it eroded easily and its productive portions were quickly swept into watercourses.

Summarily, therefore, it may be stated with confidence that the increase in flood tendency shown so unmistakably is due in by far the largest measure to the denudation of forest areas.

Diagrams on pages 13 to 16 are expressions of progressive changes in flood occurrence during the series of years indicated thereon. They are all drafted on a uniform basis, the first expression in each case being a record of the annual precipitation in inches; the second gives the number of days in each year that the gage at the point designated registered above a certain stage; the third is a combination of the first two and gives the relation of the number of days of flood to the precipitation. Thus, there is given in one expression the actual trend of flood occurrence in terms of precipitation. This form of expression eliminates one variable in the conditions governing flood occurrence, and the only remaining ones to be considered are vegetation and artificial agencies, as discussed in previous paragraphs.

The second series of diagrams on each sheet gives the same relations except that the amounts are united into progressive decades, or in one case into progressive five-year periods. This form of expression serves to neutralize the variability that occurs in the successive years and gives to the whole diagram a progressive trend which is more comprehensive and more easily interpreted than the statement of actual amounts. Thus, in the diagram on page 13, the first progressive period covers the interval from 1885 to 1894, the second that from 1886 to 1895, and so on, each period representing ten years, and the total amount of rainfall and the total number of days of flood for each decade are expressed, rather than the average amount of these quantities.

In interpreting diagrams of this kind it should be emphasized that the amounts actually shown are not significant, save as they indicate the relative trend of the successive decades. In other words, the diagrams indicate direction, and should be so interpreted.

The data given on the above-mentioned sheets relate to the upper Ohio drainage area, and they show the relation of flood occurrence on the three principal tributaries thereof—the Allegheny, Youghiogheny, and Monongahela rivers—to flood occurrence on the Ohio at Wheeling. It will be seen that in each case there has been a marked increase in the number of days of floods, and the four diagrams can be consistently compared. At Wheeling during the period 1885 to 1907, inclusive, the ratio of flood occurrence to annual precipitation

increased from 0.38 in the first half of the period to 0.48 in the second half, and this relation is shown more distinctly in the similar expression with the amounts given in totals for progressive decades. The gage records on the Allegheny at Freeport, Pa., show an increase in this ratio from 0.86 in the first half to 1.04 in the second half of the period 1874 to 1907, inclusive. The Monongahela record shows an increase of ratio during the period 1886 to 1907, inclusive, from 0.49 in the first half to 0.55 in the second half, while a still greater divergence is noted on the Youghiogheny, the ratio for the period 1875 to 1906, inclusive, increasing from 0.35 in the first half to 0.47 in the second half.

Altogether, these diagrams are extremely significant in showing the progressive increase in flood occurrence on a drainage area the deforestation of which has been constant and rapid for the past thirty years. It began first on the Allegheny and the results are apparent in the diagrams. Subsequently, timber cutting began on the Monongahela and Youghiogheny areas and is occurring at the present time.

Similar results are shown on pages 17 to 19, which give the same data for Wateree River above Camden, S. C., the Savannah above Augusta, Ga., and the Alabama above Selma, Ala.

Page 20 illustrates a record of flood duration on Connecticut River at Holyoke, Mass. This river basin has been subject to continuous deforestation for a long period. Recent testimony shows that for the last twenty years from 50,000,000 to 80,000,000 feet B. M. of timber have been released over the dam at Turners Falls annually. Records of private logging are not available, but it is known that the deforestation of the drainage area commenced some time previous to this period.

There is one point of objection that may reasonably be taken to the diagrams above discussed. It is that they draw comparison between annual precipitation and the number of days of flood. A better comparison would be one between the number and depth of flood-producing rains and the number of flood days. Such a comparison has been made on the Tennessee basin above Chattanooga. No other basins are here dealt with in this way because of the enormous amount of labor involved.

In addition to proving beyond controversy the increase in floods due to deforestation, the record is of interest because it shows how futile and misleading is the attempt to derive conclusions from flood records without taking into account records of precipitation. Inspection of the Chattanooga flood record shows a decided decrease in the number and duration of floods during the period of record. If this were taken alone, it would controvert the forest-control idea. A comparison of the precipitation records on the drainage area,

however, assures us that the rainfall has decreased, even to a greater relative extent than the floods. The final result is that the flood tendencies have increased.

The results for the Tennessee basin cover 24 years, from 1884 to 1907, inclusive. Although the records of gage height extend further back than the earlier date, the number of rainfall stations maintained on the basin previous thereto is not sufficient to render safe any conclusions with reference to precipitation. It is appreciated that a given depth of rainfall precipitated during the winter months will generally produce a greater run-off than the same depth would produce in August or September. Therefore an effort has been made to eliminate this source of error. Summing up the flood-producing rains for the 24-year period it is found that the total is 335, of which 313 occurred from December to May, inclusive, and the remaining 22 during the other portion of the year. It is apparent that the number of such rains from June to November is not sufficient to afford a basis of comparison. Therefore only the December to May floods will be considered. In making this comparison the ideal condition would be to compare the rainfalls and floods during identical conditions of climate, but such a refinement is impossible. On the other hand, the multiplication of data afforded by the large number of flood-producing storms in the December to May periods warrants the conclusion that the varying climatic conditions in this period are compensated, and the final conclusions drawn from the result must be worthy of confidence. On dividing the period covered by these 313 floods equally, two consecutive 12-year periods are afforded, which give a basis of comparison. The floods in the later period, resulting from a given depth of storm precipitation, are clearly shown to be more severe than in the earlier period. The method of presentation further makes it possible to compute the increase in flood tendency due to deforestation in the Tennessee.

The relation between storms and floods in the Tennessee basin during the periods December–May, inclusive, 1884–1895 and 1896–1907.

Period.	Storms in inches precipitated.											
	1 to 1.5.		1.5 to 2.		2 to 2.5.		2.5 to 3.		3 to 3.5.		3.5 to 4.	
	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.
1884–1895	7	5	12	6	6	15	5	9	5	13	6	30
1896–1907	8	3	11	10	9	23	11	30	4	13	1	6

The relation between storms and floods in the Tennessee basin during the periods December–May, inclusive, 1884–1895 and 1896–1907—Continued.

Period.	Storms in inches precipitated.											
	4 to 4.5.		4.5 to 5.		5 to 5.5.		6 to 6.5.		7 to 7.5.		8 to 8.5.	
	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.
1884–1895	1	6	2	17	2	18	.....	.....	2	28	.....	.....
1896–1907	1	8	3	20	.....	.....	1	11	.....	.....	1	17

If we now divide the number of flood days by the number of storms, the result will be the number of days per storm. Applying this to each of the series in the above table, the following result is reached:

Days of flood per storm.

Period.	Storms in inches precipitated.							
	1 to 1.5.	1.5 to 2.	2 to 2.5.	2.5 to 3.	3 to 3.5.	3.5 to 4.	4 to 4.5.	4.5 to 5.
1884–1895	0.7	0.5	2.5	1.8	2.6	5	6	8.1
1896–1907	.4	.9	2.6	2.7	3.2	6	8	6.7
Percentage increase	−43	80	4	50	22	20	33	−17

The algebraic sum of the above percentages is 149.00 and the average is 18.75, which sums up the effect of deforestation on run-off from 1884 to 1907, inclusive.

FLOOD DAMAGES.

A complete census of flood damages for any year or series of years has never been attempted. Therefore, it will be impossible to present any figures for which precision may be claimed. The damages for particular floods in certain areas have from time to time and for one or another purpose been assembled and, in a few places, examinations have been made with great care by commissions and boards especially qualified for such work. The results of such examinations may be taken to form a basis for an estimate; but, for the present purpose, a better basis has been made available. During the present year the Geological Survey has made inquiry of all the railroads in the United States concerning flood losses during the period January 1, 1900, to August, 1908. The railroads were selected for this purpose because it is well known that they are, by reason of their location and extent, subject to far greater physical damage than any other single interest, and it was believed that from the figures so procured a fairly representative basis of estimate might be obtained. From previous studies of this matter it appeared that the railroad

losses resulting from floods amount to about 10 per cent of the total physical loss arising therefrom, excluding, of course, the largest single item of loss, which is the depreciation of realty values arising from flood menace. The figures here presented will therefore exclude all consideration of this kind of loss.

The proportion of 10 per cent was arrived at from three points of view:

First. It has been the observation of the writer that, as a rule, the reported losses to railroads from floods have amounted to about this proportion.

Second. The actual investigations of flood losses, made by appraisal boards, and individual property returns covering fairly wide areas have approximated this proportion. Undoubtedly the most complete and comprehensive investigation of this kind was carried on by the northern New Jersey flood commission in 1903, after the great flood that arose in October of that year along Passaic River. The region comprehended in this investigation may be considered a typical one. It comprised the usual proportion of farm lands, city areas, highway bridges, railroad property, etc., and the proportion of railroad loss there was almost exactly 10 per cent of the total.

Third. One-tenth of the wealth of the United States consists of railroad property. This proportion was therefore used in the following estimates.

During each of the periods above named the returns from the railroads involved a varying percentage of the total mileage of the country. The mileage involved in each yearly estimate has been expressed as a percentage of the total mileage for that year, as given in the reports of the Interstate Commerce Commission. The several amounts were increased from the percentage that they represented to 100 per cent, to cover the entire mileage of the country. Inspection of the returns showed that this was a fair and reasonable method, because the reports were well distributed and represented a true proportion of that which might be expected to be the damage on the total mileage. This figure was then considered as 10 per cent of the total damage for the whole country and increased accordingly. The results are given in the following table:

Year.	Damage reported.	Percentage of total mileage reported.	Total railroad damage.	Estimated total damage.
1900	$666,253	14.6	$4,567,500	$45,675,000
1901	958,740	21.1	4,543,800	45,438,000
1902	1,225,468	22.2	5,520,100	55,201,000
1903	2,654,192	27.3	9,722,000	97,220,000
1904	2,476,724	31.3	7,884,100	78,841,000
1905	3,286,324	33.3	9,858,972	98,589,720
1906	2,727,511	37.3	7,312,400	73,124,000
1907	4,623,106	39.1	11,823,800	118,238,000
1908	6,517,577	27.4	23,786,000	237,860,000

STORAGE OF FLOOD WATERS.

In the northeastern portion of the country there has been a large installation of reservoirs and a consequent saving of enormous amounts of flood water. The numerous lakes in that part of the United States, irrespective of those that have been developed artificially, have a beneficial effect. It is probable that 10 per cent of the flood waters that originate in New York and New England are saved by storage in artificial reservoirs, lakes, and ponds. In Minnesota, at the head of upper Mississippi River, practically the entire flood drainage from an extensive area is conserved. In the arid West there has been an extensive installation of reservoirs, some of which conserve practically all the flood waters on their respective basins. Considering the country as a whole, however, it is doubtful if more than 1 per cent of the flood water is saved.

The storage of floods is effected by forests and similar surface vegetation and by artificial reservoirs. The amount stored by forests is and probably will for a long time to come be indeterminate, since the forest is merely an agent in assisting the ground to absorb the water. The storage is therefore essentially ground storage and the ability of the forest to enhance this is dependent absolutely on the character of the soil beneath the forest. Therefore, to fully answer the question, "To what extent could flood waters be stored by forests?" it would be necessary to consider minutely the absorption properties of the various kinds of land surface in the United States. It will be possible at some future time to give an approximate and exceedingly useful reply to this question; but before that time arrives we must have more long-term gage records on our rivers. The diagrams presented with this paper (pp. 13 to 20) constitute as useful records as there are extant in the country, and a short consideration of them will plainly reveal the fact that, while they are exceedingly useful in indicating the trend of flood duration and frequency, they do not yet yield sufficient information to give even the widest approximation of the amount of water or the proportion of run-off that can be conserved.

The question is therefore one for the future, and our stream investigations should be carried on with this as one of the purposes in view.

The extent to which flood waters could be stored by reservoirs depends on the available reservoir capacity in the several river basins. As a rule, the more diversified the character of these basins, especially in contour, the greater facilities they afford for reservoir storage.

There is a great portion of the Mississippi Valley in which floods are not subject to correction under the reservoir plan. This is also

true of certain coastal-plain streams like the Brazos and Colorado. It is probable that the streams draining one-third of the area of the United States must forever be subject to floods, and the only treatment that now appears feasible for these streams is the construction of levee systems. For the remaining two-thirds of the United States, investigations so far made indicate that from 55 to 60 per cent of the flood waters can be saved by the utilization of maximum storage capacity. Although the cost of such construction would be enormous in the aggregate, it is apparent that the saving that would accrue from relief from flood damages alone would soon return the entire investment. A glance at the estimated flood damages in the United States, page 25, shows the possibilities. In this connection it should be stated that in by far the larger proportion of the basins a saving of 55 to 60 per cent of the flood waters would insure practically entire relief from flood damages. It is not necessary to prevent floods absolutely; or, in other words, it is not necessary to secure uniformity of flow in any river in order to secure relief from flood damages. The construction of the reservoirs necessary to prevent floods would, under proper management, involve an increase in the water-power possibilities of the United States equal to about 60,000,000 horsepower. In the arid West the construction of reservoirs for flood prevention would provide water sufficient for the reclamation of many million acres of now worthless land. All of this, together with the assistance that such reservoirs would lend to navigation, constitutes the saving that would accrue from their construction. We are unable at the present time even to approximate the total figure, and therefore it must be summed up in the term "vast."

DEVELOPED WATER POWERS.

Compiled by the Bureau of the Census, under the direction of W. M. Steuart, Chief Statistician for Manufactures.

Discussion by M. O. Leighton.

SOURCES OF DATA.

A special census of the developed water powers of the United States has been made by the Bureau of the Census for the specific purposes of the conservation report. Previous inquiries of the same kind, made by this bureau, afforded a record of the names and locations of practically all the water-power developments that had taken place up to the dates thereof, and this record was used as the basis for the new census. Information concerning the developments that have been made since the date of the last census was procured through the Geological Survey, Forest Service, Bureau of Corporations, Post-Office Department, and many other agencies, both state and national. Special inquiry blanks were sent to all, including those that had figured in past censuses.

In making the new census it was necessary to procure the data in large measure by mail, and therefore it was necessary to simplify the inquiry and to secure only the facts absolutely necessary to a comprehensive summary of the developed water powers. The inquiry blank used for this purpose is reproduced below:

[Return this card to the Department of Commerce and Labor, Bureau of the Census, Washington, D. C.]

Water Power, 1908.

This office is engaged in the preparation of a report on the developed and undeveloped water power of the United States. If you use water power, please answer the following inquiries. If you do not use water power, please so state, and give the names and addresses of any power plants in your neighborhood. The card should be returned in the inclosed official envelope.

Name _____
Post-office _____ State _____
Location of plant: County _____ State _____
Name of river or stream on which plant is located _____
Number of water wheels _____ Maximum horsepower _____
Horsepower actually developed during low-water season _____
Additional power that may be developed at same point on the same river or stream, horsepower _____
Auxiliary steam power used in same plant, horsepower _____
Character of industry _____
(Give name of principal product.)
Give names and addresses of other power plants in your neighborhood _____

The character of the returns and the proportion of replies received indicate that the census is fairly complete. It is known that a greater number of the plants not accounted for in this census are of small capacity. There is, of course, some deficiency in the total; but it is believed that this is compensated by the general tendency among water-power owners to return statements based on actual wheel capacity installed rather than actual minimum power developed during the extreme low-water season. In all wheel installation it is the practice to develop above the minimum flow, and it follows that in the majority of power plants there must be a tendency to overstate the power actually developed during the lowest water. The final figures represent what is believed by those most conversant with the situation to be a reasonably accurate summary of the water power now developed in the country.

The material procured from the census has been arranged by drainage areas and combined into grand divisions, according to the plan followed in the report on undeveloped water power.

DEVELOPED POWERS.

Accompanying Table No. 1 gives a general summary of the horsepower developed in the United States and the number of wheels used for such development. It will be noted that this table gives results according to States as well as according to grand divisions.

Some interesting facts are shown. The total development in the country is 5,356,680 horsepower over 52,827 wheels, or an average development per wheel of about 100 horsepower. In the Northern Atlantic division there has been a greater water-power development than in any other, the total installation being 1,746,303 horsepower. The only other division that approaches the Northern Atlantic in development is that covering the drainage area of the St. Lawrence, including the Great Lakes, where there has been a development of 1,018,283 horsepower. The great power development in the Northern Atlantic division may largely be explained by the fact that the use of water power therein began at an earlier period than in any other divison. New England and the Middle Atlantic States are and have been essentially manufacturing in character, and water-power development has followed as a matter of course. It is also true that the presence of good powers in large numbers in this region has encouraged such development.

Comparisons of wheel capacities installed in various parts of the country are interesting. While the total figures show that the average power per wheel is 100 horsepower, the units in the various districts vary as follows:

Division.	Unit capacity horsepower per wheel.	Division.	Unit capacity horsepower per wheel.
Northern Atlantic	80	St. Lawrence	148
Southern Atlantic	77	Colorado River	261
Eastern Gulf of Mexico	42	Southern Pacific	515
Western Gulf of Mexico	47	Northern Pacific	295
Eastern Mississippi	60	Interior drainage	328
Western Mississippi	139	Arctic Ocean	125

The large number and small unit capacity of wheels in the eastern part of the country compared with the smaller number and larger capacity in the western portions, including, especially, the rivers draining from the Rocky Mountains and the Sierras, may be explained: First, by the fact that in the eastern and central portions of the country the power privileges are of smaller capacity; and second, by the fact that in the eastern portions of the country a large number of the powers were installed at an early date, when it was the rule to establish small units. More recent practice has involved the establishment of larger units, and as the western installations are all recent, this practice, taken together with the existence of larger power privileges, gives the result that might be expected from a general survey of the situation.

Table 1 shows that New York State has the largest water-power development, the total being 885,862 horsepower. It is proper to add that the Niagara powers on the New York side assist largely in making up this figure. The second State in water-power development is California, the total being 466,774 horsepower, over 1,070 wheels, or a unit installation of about 436 horsepower. Water-power development in California is comparatively recent. The third State is Maine, with 343,096 horsepower, over 2,797 wheels, or an average of 123 horsepower per wheel. As the use of water power in this State is comparatively ancient, the contrast in unit capacity between it and California is significant.

Among the other interesting points is the fact that, although, as shown by the report on undeveloped water power, the Northern Pacific division can be made to furnish about one-third of the total minimum horsepower of the country, there is at the present time a development of only 450,000 horsepower, which indicates clearly that the most fertile field for power development remaining in the United States is this northwestern country.

Table 2 gives the installations by districts and drainage areas, special comment concerning which is unnecessary.

Census returns show that, out of a total of 31,537 powers reported, 602 are of capacity of 1,000 horsepower or more. Recent progress in water-power development has been marked by great installations.

In former years the aggregate water power utilized in the country was made up largely of small units, which, while useful for local purposes and worthy of development, are not relatively important in the great question of power economics. The following summary gives the distribution of the powers of 1,000 horsepower and greater capacity, and it shows clearly that what was formerly believed to be an uncommonly great installation must now be considered a comparatively small feature.

Capacity distribution of powers of 1,000 horsepower and more.

1,000 to 5,000	459
5,000 to 10,000	65
10,000 to 15,000	27
15,000 to 20,000	13
20,000 to 25,000	17
25,000 to 40,000	11
40,000 to 60,000	4
60,000 to 100,000	3
100,000 and over	3
Total	602

Number of water powers by States and Territories, 1908.

United States	31,537	Missouri	277
		Montana	94
Alabama	1,382	Nebraska	157
Alaska	31	Nevada	32
Arizona	29	New Hampshire	876
Arkansas	203	New Jersey	560
California	559	New Mexico	48
Colorado	230	New York	3,148
Connecticut	893	North Carolina	2,614
Delaware	119	North Dakota	9
District of Columbia	1	Ohio	480
Florida	166	Oklahoma	25
Georgia	1,596	Oregon	345
Idaho	199	Pennsylvania	3,721
Illinois	155	Rhode Island	191
Indiana	222	South Carolina	846
Iowa	207	South Dakota	45
Kansas	118	Tennessee	1,793
Kentucky	691	Texas	147
Louisiana	64	Utah	200
Maine	1,222	Vermont	1,148
Maryland	496	Virginia	2,243
Massachusetts	1,370	Washington	322
Michigan	657	West Virginia	525
Minnesota	195	Wisconsin	580
Mississippi	273	Wyoming	33

TABLE 1.—*General summary—Drainage basins by States.*

States.	Northern Atlantic.		Southern Atlantic.		Gulf of Mexico.				Mississippi River.			
					Eastern.		Western.		Tributaries from the east.		Tributaries from the west.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
United States	21,864	1,746,303	5,938	459,652	3,342	139,758	258	12,071	8,959	537,080	2,385	331,739
Alabama					1,539	56,603			265	105,091		
Alaska												
Arizona												
Arkansas											255	5,868
California												
Colorado							13	937			146	26,279
Connecticut	1,546	118,145										
Delaware	277	7,976										
District of Columbia	6	1,000										
Florida			13	420	194	4,119						
Georgia			854	90,036	1,307	74,255			153	2,296		
Idaho												
Illinois									413	50,116		
Indiana									298	11,525		
Iowa											461	17,304
Kansas											184	18,606
Kentucky									834	14,156		
Louisiana					35	615	22	296			22	273
Maine	2,797	343,096										
Maryland	679	21,403							15	312		
Massachusetts	2,749	260,182										
Michigan												
Minnesota									100	15,925	361	82,007
Mississippi					267	4,166			69	3,756		
Missouri											397	10,107
Montana											162	140,494
Nebraska											227	12,792
Nevada												
New Hampshire	1,799	183,167										
New Jersey	902	38,011										
New Mexico							32	939			13	251
New York	3,046	304,003							87	3,167		
North Carolina			3,049	140,918					926	21,366		
North Dakota												
Ohio									682	26,291		

Oklahoma													29	2,994
Oregon														
Pennsylvania	5,046	273,426									530	16,849		
Rhode Island	387	37,165												
South Carolina			1,301	207,242										
South Dakota													68	11,112
Tennessee											2,160	95,060		
Texas							190	9,899					5	67
Utah														
Vermont	1,047	90,672												
Virginia	1,440	59,129	721	21,036							850	19,958		
Washington														
West Virginia	143	8,928									529	11,572		
Wisconsin											1,048	139,640		
Wyoming													55	3,585

States.	St. Lawrence River.		Colorado River.		Southern Pacific.		Northern Pacific.		Interior drainage.		Arctic Ocean.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
United States	6,896	1,018,283	285	74,428	822	423,707	1,659	[a] 489,454	353	115,944	66	8,261	52,827	5,356,680
Alabama													1,804	161,694
Alaska							106	17,289					106	17,289
Arizona			37	16,855									37	16,855
Arkansas													255	5,868
California					820	423,597	176	25,440	74	17,737			1,070	466,774
Colorado			194	51,662									353	78,878
Connecticut													1,546	118,145
Delaware													277	7,976
District of Columbia													6	1,000
Florida													207	4,539
Georgia													2,314	166,587
Idaho							261	60,533	24	18,210			285	78,743
Illinois													413	50,116
Indiana	197	17,628											495	29,153
Iowa													461	17,304
Kansas													184	18,606
Kentucky													834	14,156
Louisiana													79	1,184
Maine													2,797	343,096
Maryland													694	21,715
Massachusetts													2,749	260,182
Michigan	1,498	205,019											1,498	205,019
Minnesota	20	46,800									50	7,648	531	152,380
Mississippi													336	7,922

[a] Includes Alaska.

TABLE 1.—*General summary—Drainage basins by States*—Continued.

States.	St. Lawrence River.		Colorado River.		Southern Pacific.		Northern Pacific.		Interior drainage.		Arctic Ocean.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
Missouri							42	7,558					397	10,107
Montana													204	148,052
Nebraska													227	12,792
Nevada			1	3			7	252	31	20,322			39	20,577
New Hampshire													1,799	183,167
New Jersey													902	38,011
New Mexico			10	1,120									56	2,310
New York	3,380	578,692											6,513	885,862
North Carolina													3,975	162,284
North Dakota											16	613	16	613
Ohio	191	8,549											873	34,840
Oklahoma													29	2,994
Oregon					2	110	586	231,203	2	66			590	231,379
Pennsylvania	20	715											5,596	290,990
Rhode Island													387	37,165
South Carolina													1,301	207,242
South Dakota													68	11,112
Tennessee													2,160	95,060
Texas													195	9,966
Utah			38	4,656					222	59,609			260	64,265
Vermont	971	79,604											2,018	170,276
Virginia													3,011	100,123
Washington							475	147,041					475	147,041
West Virginia													672	20,500
Wisconsin	619	81,276											1,667	220,916
Wyoming			5	132			6	138					66	3,855

TABLE 2.—*Drainage basins in the United States.*

I. NORTHERN ATLANTIC

Drainage basins.	Maine.		New Hampshire.		Vermont.		Massachusetts.		Connecticut.		Rhode Island.		New York.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	2,797	343,096	1,799	183,167	1,047	90,672	2,749	260,182	1,546	118,145	387	37,165	3,046	304,003
St. Johns River	147	13,681												
St. Croix River	89	20,500												
Penobscot River	518	70,454												
Kennebec River	659	63,936												
Androscoggin River	590	101,355	93	22,100										
Presumpscot River	179	20,569												
Saco River	169	22,302	68	3,030										
Merrimac River			877	90,082			589	71,251						
Connecticut River			574	50,977	929	85,512	1,117	123,309	490	33,101				
Blackstone River							182	14,111			156	17,324		
Thames River							88	8,499	478	45,214	1	25		
Housatonic River							138	14,206	364	31,685			17	459
Hudson River					118	5,160	54	5,245					2,083	275,125
Passaic River													30	775
Raritan River														
Delaware River													208	5,924
Susquehanna River													645	20,187
Potomac River														
James River														
Minor streams (Chesapeake Bay)														
Minor streams (northern Atlantic)	446	30,299	187	16,978			581	23,561	214	8,145	230	19,816	63	1,533

TABLE 2.—*Drainage basins in the United States*—Continued.

I. NORTHERN ATLANTIC—Continued.

Drainage basins.	New Jersey.		Delaware.		Pennsylvania.		Maryland.		Virginia.		West Virginia.		District of Columbia.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	902	38,011	277	7,976	5,046	273,426	679	21,403	1,440	59,129	143	8,928	6	1 000	21,864	1,746,303
St. Johns River															147	13,681
St. Croix River															89	20,500
Penobscot River															518	70,454
Kennebec River															659	63,936
Androscoggin River															683	123,455
Presumpscot River															179	20,569
Saco River															237	25,332
Merrimac River															1,466	161,333
Connecticut River															3,110	292,899
Blackstone River															338	31,435
Thames River															567	53,738
Housatonic River															519	46,350
Hudson River	17	680													2,272	286,210
Passaic River	179	12,805													209	13,580
Raritan River	204	6,309													204	6,309
Delaware River	427	15,327	167	5,314	1,616	47,649									2,418	74,214
Susquehanna River					3,233	222,530	71	2,217							3,949	244,934
Potomac River					197	3,247	260	4,766	462	11,457	142	8,920	6	1,000	1,067	29,390
James River									607	40,165	1	8			608	40,173
Minor streams(Chesapeake Bay)			35	901			346	14,389	363	7,429					744	22,719
Minor streams (northern Atlantic)	75	2,890	75	1,761			2	31	8	78					1,881	105,092

II. SOUTHERN ATLANTIC.

Drainage basins.	Virginia.		South Carolina.		North Carolina.		Georgia.		Florida.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	721	21,036	1,301	207,242	3,049	140,918	854	90,036	13	420	5,938	459,652
Chowan River	113	2,381			64	1,147					177	3,528
Roanoke River	607	18,647			198	17,419					805	36,066
Tar River					166	6,431					166	6,431
Neuse River					317	11,365					317	11,365
Cape Fear River					673	27,539					673	27,539
Pedee (Yadkin) River			228	7,867	1,124	50,432					1,352	58,299
Santee River			573	179,708	478	26,028					1,051	205,736
Savannah River			294	16,178			245	43,357			539	59,535
Ogeechee River							88	1,965			88	1,965
Altamaha River							506	44,531			506	44,531
Minor streams (southern Atlantic)	1	8	206	3,489	29	557	15	183	13	420	264	4,657

III. EASTERN GULF OF MEXICO.

Drainage basins.	Florida.		Georgia.		Alabama.		Mississippi.		Louisiana.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	194	4,119	1,307	74,255	1,539	56,603	267	4,166	35	615	3,342	139,758
Suwanee River	16	265	29	962							45	1,227
Apalachicola River	36	565	784	62,991	114	7,717					934	71,273
Mobile River:												
Tombigbee River					340	5,193	79	1,097			419	6,290
Alabama River			464	9,869	799	37,892					1,263	47,761
Pearl River							86	1,532	18	312	104	1,844
Minor streams (eastern Gulf of Mexico)	142	3,289	30	433	286	5,801	102	1,537	17	303	577	11,363

TABLE 2.—*Drainage basins in the United States*—Continued.

IV. WESTERN GULF OF MEXICO.

Drainage basins.	Louisiana.		Texas.		New Mexico.		Colorado.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	22	296	190	9,899	33	939	13	937	258	12,071
Sabine River	11	126	24	263					35	389
Neches River			35	538					35	538
Trinity River			12	279					12	279
Brazos River			13	448					13	448
Colorado River (of Texas)			25	1,503					25	1,503
Guadalupe River			69	6,447					69	6,447
San Antonio River			6	215					6	215
Nueces River			3	36					3	36
Rio Grande			1	102	16	370	13	937	30	1,409
Pecos River			2	68	17	569			19	637
Minor streams (western Gulf of Mexico)	11	170							11	170

V. MISSISSIPPI RIVER (TRIBUTARIES FROM THE EAST).

Drainage basins.	Mississippi.		Alabama.		Georgia.		Tennessee.		North Carolina.		Virginia.		West Virginia.		Kentucky.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	69	3,756	265	105,091	153	2,296	2,160	95,060	926	21,366	850	19,958	529	11,572	834	14,156
Yazoo River																
Minor eastern tributaries, lower Mississippi River	61	709					62	796							4	67
Ohio River:																
Tennessee River	8	3,047	265	105,091	153	2,296	1,691	85,548	710	19,260	378	6,214			8	103
Cumberland River							397	8,576							284	4,431
Green River							10	140							205	3,634
Kentucky River															158	2,916
Licking River															52	928
Big Sandy River											20	261	20	320	91	924
Kanawha River									216	2,106	452	13,483	282	7,023		
Monongahela River													129	2,324		
Youghiogheny River													3	50		
Minor southern tributaries													95	1,855	32	1,153
Allegheny River																
Beaver River																
Muskingum River																
Scioto River																
Great Miami River																
Wabash River																
Minor northern tributaries																
Illinois River																
Rock River																
Wisconsin River																
Chippewa River																
St. Croix River																
Minor eastern tributaries, upper Mississippi River																

TABLE 2.—*Drainage basins in the United States*—Continued.

V. MISSISSIPPI RIVER (TRIBUTARIES FROM THE EAST)—Continued.

Drainage basins.	Pennsylvania.		Ohio.		Indiana.		Illinois.		Wisconsin.		Minnesota.		New York.		Maryland.		Total for drainage basins.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower	Wheels.	Horsepower.	Wheels.	Horsepower.
	530	16,849	682	26,291	298	11,525	413	50,116	1,048	139,640	100	15,925	87	3,167	15	312	8,959	537,080
Yazoo River																		
Minor eastern tributaries, lower Mississippi River																	127	1,572
Ohio River:																		
Tennessee River																	3,213	221,559
Cumberland River																	681	13,007
Green River																	215	3,774
Kentucky River																	158	2,916
Licking River																	52	928
Big Sandy River																	131	1,505
Kanawha River																	950	22,612
Monongahela River	18	262															147	2,586
Youghiogheny River	56	1,205													15	312	74	1,567
Minor southern tributaries	3	70															130	3,078
Allegheny River	331	8,146											87	3,167			418	11,313
Beaver River	121	7,154	44	2,320													165	9,474
Muskingum River			204	8,880													204	8,880
Scioto River			69	2,045													69	2,045
Great Miami River			187	8,245	27	1,224											214	9,469
Wabash River					238	9,993	4	72									242	9,665
Minor northern tributaries	1	12	178	4,801	24	465	6	118									209	5,396
Illinois River					9	243	222	36,162	29	893							260	37,298
Rock River							167	13,214	210	10,967							377	24,181
Wisconsin River									476	74,491							476	74,491
Chippewa River									157	24,976							157	24,976
St. Croix River									58	11,025	13	1,750					71	12,775
Minor eastern tributaries, upper Mississippi River							14	550	118	17,288	87	14,175					219	32,013

VI. MISSISSIPPI RIVER (TRIBUTARIES FROM THE WEST).

Drainage basins.	Louisiana.		Arkansas.		Texas.		Oklahoma.		New Mexico.		Colorado.		Kansas.		Missouri.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	22	273	255	5,868	5	67	29	2,994	13	251	146	26,279	184	18,606	397	10,107
Minnesota River																
Wapsipinicon River																
Des Moines River																
Missouri River:																
Big Sioux River																
James River																
Milk River																
Marias River																
Jefferson River																
Madison River																
Gallatin River																
Minor northern tributaries															38	938
Musselshell River																
Yellowstone River																
Little Missouri River																
Cheyenne River																
White River																
Niobrara River																
Platte River											126	21,803				
Kansas River											1	75	122	10,192		
Osage River													1	18	71	1,448
Minor southern tributaries													1	15	31	502
Arkansas River			74	1,100							19	4,401	22	1,205	194	5,874
Cimarron River:																
Canadian River							7	291	13	251						
Minor tributaries			108	3,797			4	160					38	7,176		
Red River	22	273	73	971	5	67	18	2,543								
Minor western tributaries Mississippi River															63	1,345

TABLE 2.—*Drainage basins in the United States*—Continued.

VI. MISSISSIPPI RIVER (TRIBUTARIES FROM THE WEST)—Continued.

Drainage basins.	Iowa.		Nebraska.		Wyoming.		Montana.		South Dakota.		Minnesota.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	461	17,304	227	12,792	55	3,585	162	140,494	68	11,112	361	82,007	2,385	331,739
Minnesota River											40	1,712	40	1,712
Wapsipinicon River	54	1,655											54	1,655
Des Moines River	27	1,360									3	198	30	1,558
Missouri River:														
Big Sioux River	8	261							15	3,115			23	3,376
James River									20	411			20	411
Milk River														
Marias River														
Jefferson River							38	20,619					38	20,619
Madison River							13	17,336					13	17,336
Gallatin River							6	405					6	405
Minor northern tributaries	62	2,274					44	67,215	11	231			155	70,658
Musselshell River														
Yellowstone River					19	1,389	26	6,224					45	7,613
Little Missouri River														
Cheyenne River					20	331			22	7,355			42	7,686
White River			1	30									1	30
Niobrara River			30	950									30	950
Platte River			74	5,572	16	1,865							216	29,240
Kansas River			89	5,156									212	15,423
Osage River													72	1,466
Minor southern tributaries			33	1,084			35	28,695					100	30,296
Arkansas River													309	12,580
Cimarron River:														
Canadian River													20	542
Minor tributaries													150	11,133
Red River													118	3,854
Minor western tributaries Mississippi River	310	11,754									318	80,097	691	93,196

VII. ST. LAWRENCE RIVER.

Drainage basins.	Minnesota.		Wisconsin.		Michigan.		Indiana.		Ohio.		Pennsylvania.		New York.		Vermont.		Total.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	20	46,800	619	81,276	1,498	205,019	197	17,628	191	8,549	20	715	3,380	578,692	971	79,604	6,896	1,018,283
Lake Superior	20	46,800	6	2,227	73	34,775											99	83,802
Lake Michigan			613	79,049	963	145,179	172	16,463									1,748	240,691
Lake Huron					213	13,878											213	13,878
St. Clair River					85	3,331											85	3,331
Lake Erie					164	7,856	25	1,165	191	8,549	17	593	129	4,838			526	23,001
Niagara River													103	191,426			103	191,426
Lake Ontario											3	122	2,025	209,368			2,028	209,490
Lake Champlain (Richelieu River)													373	50,345	971	79,604	1,344	129,949
Minor St. Lawrence tributaries													750	122,715			750	122,715

VIII. COLORADO RIVER.

Drainage basins.	Arizona.		New Mexico.		Colorado.		Wyoming.		Utah.		Nevada.		Total.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	37	16,855	10	1,120	194	51,662	5	132	38	4,656	1	3	285	74,428
Gila River	26	16,611	7	995									33	17,606
Williams River	1	9											1	9
Little Colorado River	8	185											8	185
San Juan River			3	125	45	18,260							48	18,385
Grand River					145	32,132			1	6			146	32,138
Green River					4	1,270	5	132	17	3,378			26	4,781
Fremont River									4	93			4	90
Virgin River									9	188	1	3	10	193
Minor tributaries	2	50							7	991			9	1,041

TABLE 2.—*Drainage basins in the United States*—Continued.

IX. SOUTHERN PACIFIC.

Drainage basins.	California.		Oregon.		Total.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	820	423,597	2	110	822	423,707
Minor streams	74	50,183			74	50,183
San Francisco Bay	11	6,455			11	6,455
Sacramento River	576	280,735	2	110	578	280,845
San Joaquin River	159	86,224			159	86,224

X. NORTHERN PACIFIC.

Drainage basins.	Oregon.		Idaho.		Wyoming.		Montana.		Washington.		California.		Nevada.		Total.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	586	231,203	261	60,533	6	138	42	7,558	475	147,041	176	25,440	7	252	[a] 1,553	[a] 472,165
Columbia River:																
Willamette River	299	92,531													299	92,531
Des Chutes River	17	60,832													17	60,832
John Day River	24	22,083													24	22,083
Snake River	55	35,771	186	36,402	6	138			28	4,728			7	252	282	77,291
Spokane River			70	23,176					33	14,473					103	37,649
Pend Oreille (Clark Fork)			2	600			37	6,838	7	237					46	7,675
Yakima River									52	8,838					52	8,838
Minor tributaries	55	10,176							186	33,099					241	43,275
Kootenai River			3	355			5	720							8	1,075
Puget Sound									139	84,270					139	84,270
Minor streams, northern Pacific	136	9,810							30	1,396	176	25,440			342	36,646

[a] Exclusive of Alaska, with 106 wheels, of 17,289 horsepower.

XI. GREAT BASIN.

Drainage basins.	Utah.		Nevada.		California.		Oregon.		Idaho.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	222	59,609	31	20,322	74	17,737	2	66	24	18,210	353	115,944
Wasatch Mountains drainage	222	59,609							24	18,210	246	77,819
Humboldt River			31	20,322			2	66			33	20,388
Sierra Nevada drainage					74	17,737					74	17,737
Minor streams in Great Basin												

XII. HUDSON BAY.

Drainage basins.	North Dakota.		Minnesota.		Total.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	16	613	50	7,648	66	8,261
Red River of the North	16	613	50	7,648	66	8,261
St. Marys River						

UNDEVELOPED WATER POWERS.

By M. O. Leighton.

The surveys and examinations necessary to a thorough and accurate report of the water-power resources of the United States have never been completed. In certain parts of the country the facts are sufficiently well known to make it possible to present a tolerably accurate statement. In other parts the information is fragmentary, and therefore power estimates must be considered approximate. Taken as a whole, however, the schedule here appended will be sufficient for the purposes for which it was prepared.

In order to present the information in a systematic way, the drainage areas of the United States have been united into groups according to geographic distribution. These group boundaries have been arbitrarily determined according to what seems to be the most convenient arrangement for the purposes of this report. The grouping is as follows: Atlantic Ocean, Pacific Ocean, Arctic Ocean, and interior drainage. These groups have been subdivided into 12 principal divisions, as follows: I. Northern Atlantic; II. Southern Atlantic; III. Eastern Gulf of Mexico; IV. Western Gulf of Mexico; V. Mississippi River (tributaries from the east); VI. Mississippi River (tributaries from the west); VII. St. Lawrence; VIII. Colorado River; IX. Southern Pacific; X. Northern Pacific; XI. Great Basin; XII. Hudson Bay.

SOURCES OF DATA.

The data used in this report have been obtained from the following sources:

The records of flow are mainly from the reports and files of the water-resources branch of the United States Geological Survey. As the period over which these records extend varies in length, a seven-year period, extending from 1900 to 1906, inclusive, was taken as a basis and all values of flow are the mean for these years.

The profiles and elevations have been obtained as follows:

(*a*) River surveys made by the United States Geological Survey, U. S. Army Engineer Corps, and others.

(*b*) Elevations as given by railroad and other levels.

(*c*) Dictionary of Altitudes, Bulletin No. 274, United States Geological Survey.

(*d*) United States Geological Survey topographic maps.

(*e*) Miscellaneous maps and reports of various State and other organizations.

In the use of maps the following preferences have been given: (1) United States Geological Survey topographic sheets; (2) special detailed surveys; (3) General Land Office maps; (4) United States post-route maps; (5) Rand & McNally Atlas sheets.

WATER POWER.

The schedule presented in this report gives the amount of available water power according to three classifications—(1) that which may be produced by the minimum flow; (2) the assumed maximum development; and (3) the additional power that may be recovered by developing the available storage capacity in the upland basins and using stored water to compensate the low-water periods. The data as a whole have been considered without reference to present practicability of development or present market. For the purposes of this report it has been assumed that all the power in the United States will some day be required. Such an interpretation is the logical one when natural resources are being considered. In other words, the schedule here presented must be interpreted for the future rather than for the present. The reader should not assume that all the power here shown is economically available to-day. Much of it, indeed, would be too costly in development to render it of commercial importance under the present conditions of market and the price of fuel power. The schedule shows therefore what will be the maximum possibilities in the day when our fuel shall have become so exhausted that the price thereof for production of power is prohibitive, and the people of the country shall be driven to the use of all the water power that can reasonably be produced by the streams.

Consideration has been given to all the conditions that determine the possibilities of power production on the various rivers of the country. Especially has the slope of the stream channels been scrutinized. Theoretically, of course, the energy developed by the various rivers is that produced by the total fall of the water from source to mouth, but it has not been assumed that, even under ideal conditions of market, all this power will ever be commercially available. The flatter portions of the river channels can never be profitably developed for power and they have not been included in the schedule. The rivers have been divided into sections of varying length, determined by channel slope, and the fall and flow of each

section have been obtained from the best available source of information. The records of stream flow collected by the water-resources branch of the Geological Survey have almost uniformly been the only available resort, although acknowledgments should be made to the state water-supply commissions of New York and Pennsylvania; the state engineers of New York, Colorado, California, Oregon, and Nebraska; the territorial engineer of New Mexico; the state geological surveys of Maine, New Jersey, North Carolina, Virginia, Georgia, and Wisconsin; and various other bodies and individuals, public and private, who in the past have maintained measurements in cooperation with the United States Geological Survey or independently. Use has also been made of certain river gage records of the United States Weather Bureau and of the Corps of Engineers, U. S. Army.

In determining the flow for the various sections the data of flow per square mile, procured from the sources above enumerated, have been applied. The drainage areas above the upper and the lower limits of each section have been determined and a mean taken for the whole section. This has been used as a factor along with the flow per square mile in determining the minimum flow for that section. This figure, together with 90 per cent of the total fall from head to foot, has been used to determine theoretical horsepowers, according to the usual formulas. It is obvious that in practice the entire fall along any stretch of river or at any power privilege can not be effectively utilized. In few places can even 90 per cent be utilized at the present time; but, inasmuch as these figures are supposed to cover future as well as present practice, and inasmuch as it may reasonably be assumed that future practice in water-power installation will improve, it is believed that 90 per cent of the fall along any particular power privilege or section may eventually be realized.

The results of calculations of theoretical power on 90 per cent total fall have been reduced 10 per cent to allow for inefficiency of wheels. It is recognized that 90 per cent efficiency is too high to be used in calculations of power at the present time, 75 or 80 per cent being the usual installation maximum. Here again, however, we are computing for future conditions, as well as present ones, and it may confidently be expected that, with the improvement of turbines, a greater percentage of the theoretical power will be realized on the shaft and improvements will before long render possible a 90 per cent efficiency.

In determining the minimum horsepower, the minimum flow for the lowest two consecutive seven-day periods in each year was determined and the mean of these values for the period of record was taken as the minimum flow. It is obvious that this is somewhat

higher than the absolute minimum, but the latter is usually of so short duration that it does not equal the practicable minimum that may profitably be installed.

The assumed maximum economical development has been determined on the assumption that it is good commercial practice to develop wheel installation up to that amount the continuance of which can be assured during six months of the year, on the assumption that the deficiency in power during the remainder of the year can be profitably provided by the installation of fuel power plants as auxiliaries. In many parts of the country it has been shown conclusively that it is economical to develop up to that amount which can be had continuously during the highest four months of the year, and, while it is probable that there are parts of the country where the limit should be the highest eight or ten months, it is believed that the period used in these schedules is a very conservative average. The minimum weekly flow for each month of the year has been arranged according to magnitude, and the sixth value has been taken as the basis for estimating the power, the mean of these values for the record period in each case being that used in the computations.

An endeavor has been made to determine the maximum power that might be produced if the practicable maximum storage available on the drainage areas were established. Surveys on many of the basins make possible a fairly close statement; but, inasmuch as fully three-fourths of the country has not been surveyed in a manner suitable for this purpose, only rough estimates can be given for the entire area. There are two methods by which an approximate estimate of total power can be made.

The first is to consider the power on those drainage areas for which suitable surveys are available and to increase the amount by the equivalent of the proportion left unsurveyed. An examination of the facts will show that the amount obtained by this method will be too low. It is apparent from a review of the index map showing the areas covered by such surveys that a fairly large proportion, probably one-third, comprises country in which good reservoir sites are either lacking or are uncommon in occurrence. Such portions include large parts of the Dakotas, Nebraska, Kansas, Oklahoma, Texas, and Louisiana, together with great areas on the Atlantic and Pacific coastal plains. Therefore to increase the total available water power from storage that may be computed on surveyed portions by the ratio of total surveyed portions to the entire country would hardly do justice to the situation. Nevertheless, the figures are here presented.

It is found that the total power available in the surveyed portions, including storage, is about 53,000,000 horsepower. If this be considered as one-fourth, to correspond with the portion of the country

surveyed, the total power of the country, with practical maximum storage will be about 212,000,000 horsepower.

The second method of computation involves consideration of the increase of power available from storage in the several portions of the country in which surveys have been made, and applying the ratio of increase to unsurveyed and similar country in those regions. The topographic surveys, while they cover only one-fourth of the total area of the country, have nevertheless been prosecuted in all sections, so that the storage data are applicable to all physiographic types that are comprised within the United States. Applying the information in this way, we obtain a grand total of 230,800,000 horsepower, which, it appears to the writer, is a more accurate figure than that obtained by the first method.

In any case, therefore, it may be assumed with confidence that, were all practicable storage sites utilized and the water properly applied, there might be established eventually in the country a total power installation of at least 200,000,000 horsepower and probably much more.

In the actual management of storage for water power or for any other water utilization the stored waters are released according as needed, and they must be distributed according to the condition of the river and the length of the dry season. Therefore, water from storage is required for a varying number of months, according to the climatological conditions governing the river discharge. Some assumption in this matter has been necessary, and it is believed from the experience that has been gained in the study of rivers throughout the country that it will be fair and conservative to assume that, if any given storage be considered as released uniformly during six months of the year, and the natural flow from the unconserved areas be considered as sufficient to maintain at least an equal flow during the remaining six months, the results will not depart too widely from the actual conditions as regards total power that may be achieved in practice, unless, indeed, they are too conservative. It is well known that on some rivers an economical use of stored water would involve a shorter period of total release than six months to insure the most uniform distribution of discharge. This would provide for a greater power development than the six months of distribution. Nevertheless, the latter has been considered a fair average, and has been used in the accompanying schedule.

Summing up the whole country according to the divisions thereof heretofore discussed, we obtain the general summary given below. Especial mention should be made of the fact that the results here given do not include the State of Pennsylvania, the figures for which had not been furnished up to the date of this report.

Estimate of stream flow and water power in the United States.

Principal drainages.	Drainage area in square miles.	Flow per annum in billion cubic feet.	Horsepower.	
			Minimum.	Assumed maximum development.
North Atlantic to Cape Henry, Va	159,879	8,942	1,712,050	[a]3,186,600
Southern Atlantic to Cape Sable, Fla	123,920	5,560	1,253,000	1,957,800
Eastern Gulf of Mexico to Mississippi River	142,220	6,867	559,000	963,000
Western Gulf of Mexico west of Vermilion River	[b]433,700	2,232	433,760	822,600
Mississippi River (tributaries from east)	333,600	12,360	2,619,590	[a]5,344,600
Mississippi River (tributaries from west, including Vermilion River)	905,200	9,580	3,948,970	7,085,000
St. Lawrence River to Canadian line	[c]299,720	8,583	6,682,480	8,090,000
Colorado River above Yuma, Ariz	225,000	521	2,918,500	5,546,000
Southern Pacific to Point Bonita, Cal	70,700	2,193	3,215,400	7,808,300
Northern Pacific	290,400	15,220	12,979,700	24,701,000
Great Basin	223,000	.....	518,000	801,000
Hudson Bay	62,150	614	75,800	212,600
Total	3,269,490	72,672	36,916,250	66,518,500

[a] Not including area in Pennsylvania.
[b] Includes Rio Grande in Mexico.
[c] Includes drainage in Canada.

It will be noted from the foregoing that the region furnishing by far the greatest water-power possibilities is the northern Pacific, which comprises essentially the basins of Columbia and Sacramento rivers, the power possibilities there being about one-third those of the whole United States.

The following schedules give in detail figures concerning run-off and potential water power over the various drainage areas included within the several districts:

Estimate of stream flow and water power in the United States.

I. NORTHERN ATLANTIC.[a]

Stream.	States drained.	Drainage area (square miles).	Flow from area.				Horsepower.	
			Second-feet.	Second-feet per square mile.	Per annum.		Minimum.	Assumed maximum development.
					Depth in inches.	Billion cubic feet.		
St. Johns[b]	Maine	7,500	13,200	1.76	23.90	416	30,500	73,800
St. Croix	do	1,630	4,260	2.61	35.40	134	28,700	49,000
Penobscot	do	8,500	16,700	1.96	26.60	526	157,000	298,000
Kennebec	do	5,970	11,000	1.84	25.00	347	144,000	284,000
Androscoggin	Maine, New Hampshire	3,500	7,500	2.14	29.00	236	168,000	218,000
Presumpscot	Maine	600	1,010	1.68	22.80	32	(c)	(c)
Saco	Maine, New Hampshire	1,720	4,060	2.36	32.00	128	20,900	69,000
Merrimac	New Hampshire, Massachusetts	5,020	8,140	1.62	22.00	257	111,000	190,000
Connecticut	Vermont, New Hampshire, Massachusetts, Connecticut	11,100	22,100	1.99	27.00	697	230,000	491,000
Blackstone	Massachusetts, Rhode Island	(c)	.....	(c)	(c)	(c)	5,280	12,700
Thames	Massachusetts, Connecticut, Rhode Island	(c)	.....	(c)	(c)	(c)	14,400	28,600
Housatonic	New York, Massachusetts, Connecticut	1,980	4,300	2.17	29.40	136	43,100	66,200
Hudson	New York, Massachusetts, Vermont, New Jersey	13,400	25,400	1.90	25.80	802	298,000	473,000
Passaic	New York, New Jersey	949	2,060	2.17	29.40	65	10,000	22,000
Raritan	New Jersey	1,110	2,390	2.15	29.20	75	4,370	9,710
Delaware	New York, New Jersey, Pennsylvania, Delaware	13,100	25,800	1.97	26.70	814	.....	.....
Susquehanna	New York, Pennsylvania, Maryland	27,400	42,800	1.56	21.20	1,350	.....	.....
Potomac	Maryland, Virginia, West Virginia, Pennsylvania	14,300	17,300	1.21	16.40	545	176,000	462,000
James	Virginia	10,400	14,000	1.35	18.30	442	196,000	300,000
Minor streams (Chesapeake Bay)	Virginia, Maryland	12,800	20,300	1.59	21.60	640	43,300	82,000
Minor streams (northern Atlantic)	Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland, Virginia.	18,900	41,200	2.18	29.60	1,300	31,500	57,600
Total	.....	159,879	.....	.....	.....	8,942	.....	.....

[a] St. Johns to Cape Henry, Va.

[b] Drainage in United States only.

[c] Included in minor streams (northern Atlantic).

II. SOUTHERN ATLANTIC.[a]

Chowan	Virginia, North Carolina	5,000	7,000	1.40	19.00	221	5,100	10,100
Roanoke	do	9,740	12,200	1.25	17.00	385	205,000	343,000
Tar	North Carolina	4,360	5,500	1.26	17.10	174	4,000	8,000
Neuse	do	5,550	7,320	1.32	17.90	231	5,000	10,000
Cape Fear	do	9,030	11,100	1.23	16.70	350	40,000	80,000
Pedee (Yadkin)	North Carolina, South Carolina	10,600	16,900	1.60	21.70	533	222,000	334,000
Santee	do	14,800	24,500	1.66	22.50	772	400,000	590,000
Savannah	South Carolina, Georgia	11,100	17,500	1.58	21.40	552	290,000	438,000
Ogeechee	Georgia	5,140	6,530	1.27	17.20	206	4,300	10,700
Altamaha	do	14,100	17,700	1.26	17.10	558	57,600	94,000
Minor streams (southern Atlantic)	Virginia, North Carolina, South Carolina, Georgia, Florida	34,500	50,100	1.45	19.70	1,580	20,000	40,000
Total		123,920				5,560	1,253,000	1,957,800

III. EASTERN GULF OF MEXICO.[b]

Suwanee	Florida, Georgia	9,970	15,000	1.50	20.40	473	(c)	(c)
Apalachicola	Alabama, Georgia, Florida	18,800	30,300	1.61	21.80	956	204,000	326,000
Mobile	Alabama, Georgia, Mississippi	42,100	66,200	1.57	21.30	2,090		
Tombigbee	Alabama, Mississippi						50,000	100,000
Alabama	Alabama, Georgia						275,000	487,000
Pearl	Mississippi, Louisiana	8,650	12,300	1.42	19.30	388	(c)	(c)
Minor streams (eastern Gulf of Mexico)	Florida, Alabama, Mississippi, Louisiana	62,700	93,800	1.50	20.40	2,960	30,000	50,000
Total		142,220				6,867	559,000	963,000

IV. WESTERN GULF OF MEXICO.

Sabine	Texas, Louisiana	20,700	16,700	0.807	11.00	527	2,020	5,050
Trinity	Texas	17,700	9,370	.529	7.18	295	3,180	12,800
Brazos	Texas, New Mexico	48,800	9,760	.200	2.72	308	7,460	20,900
Colorado (Texas)	do	39,000	3,790	.097	1.32	120	28,100	55,700
Guadalupe	Texas	10,500	3,750	.357	4.84	118	36,000	43,400
Rio Grande[d]	Texas, New Mexico, Colorado	248,000	7,880	.032	.43	249	267,000	545,000
Pecos	Texas, New Mexico						55,000	87,800
Minor streams (western Gulf of Mexico)	Louisiana, Texas	49,000	19,500	.398	5.40	615	35,000	52,000
Total		433,700				2,232	433,760	822,650

[a] Cape Henry, Va., to Cape Sable, Fla.
[b] Eastern Gulf of Mexico included between Cape Sable, Fla., and Mississippi River.
[c] Included in minor streams (eastern Gulf of Mexico).
[d] Includes drainage area and flow in Mexico, but does not include power.

Estimate of stream flow and water power in the United States—Continued.

V. MISSISSIPPI RIVER (TRIBUTARIES FROM THE EAST).

Stream.	States drained.	Drainage area (square miles).	Flow from area.				Horsepower.	
			Second-feet.	Second-feet per square mile.	Per annum.		Minimum.	Assumed maximum development.
					Depth in inches.	Billion cubic feet.		
Mississippi [a]		1,238,800	696,400	0.562	7.63	21,940	147,000	335,000
Eastern tributaries lower Mississippi, below Missouri River (exclusive of Ohio).		42,800	50,100	1.17	15.90	1,580	15,000	30,000
Ohio	Kentucky, Tennessee, Mississippi, Maryland, Pennsylvania, New York, Ohio, Illinois, Indiana, Alabama, Georgia, North Carolina, Virginia, West Virginia.	204,000	270,000	1.32	17.90	8,500	[b] 40,000	[b] 100,000
Tennessee	Kentucky, Tennessee, Mississippi, Alabama, Georgia, North Carolina, Virginia.						1,210,000	1,950,000
Cumberland	Kentucky, Tennessee, Virginia						76,800	159,000
Green	Kentucky, Tennessee						11,400	28,500
Kentucky	Kentucky						18,100	45,100
Licking	do						5,366	13,400
Big Sandy	Kentucky, West Virginia, Virginia						21,700	57,600
Kanawha	West Virginia, Virginia, North Carolina						402,000	1,020,000
Monongahela	West Virginia, Pennsylvania						71,000	283,000
Minor southern tributaries (Ohio)	Tennessee, Kentucky, West Virginia, Pennsylvania						31,800	7,700
Allegheny	New York, Pennsylvania							
Beaver	Pennsylvania, Ohio						6,000	18,300
Muskingum	Ohio						16,500	53,100
Scioto	do						3,630	17,200
Great Miami	Ohio, Indiana						28,700	74,600
Wabash	Indiana, Illinois						40,600	119,000
Minor northern tributaries (Ohio)	Illinois, Indiana, Ohio, Pennsylvania						10,000	41,200
Eastern tributaries, upper Mississippi, above Missouri River.	Illinois, Wisconsin, Minnesota	86,800	72,300	.833	11.30	2,280		
Illinois	Illinois						167,000	261,000
Rock	Illinois, Wisconsin						20,800	46,400
Wisconsin	Wisconsin						121,000	244,000
Chippewa	do						99,000	238,000
St. Croix	Wisconsin, Minnesota						39,000	90,000
Minor eastern tributaries upper Mississippi (above Missouri River).	Illinois, Wisconsin, Minnesota						17,200	43,200
Total		333,600				12,360		

VI. MISSISSIPPI RIVER (TRIBUTARIES FROM THE WEST).

Western tributaries upper Mississippi (above Missouri River).	Minnesota, South Dakota, Iowa, Missouri	84,700	42,500	0.501	6.79	1,340	.....	.....
Minnesota	Minnesota, South Dakota	.....	.....	.....	.....	.....	17,300	46,600
Wapsipinicon	Iowa, Minnesota	.....	.....	.....	.....	.....	4,380	10,700
Des Moines	do	.....	.....	.....	.....	.....	59,800	222,000
Minor western tributaries upper Mississippi (above Missouri River).	Minnesota, South Dakota, Iowa, Missouri	.....	.....	.....	.....	.....	132,000	275,000
Missouri [c]	Missouri, Louisiana, Minnesota, South Dakota, North Dakota, Montana, Wyoming, Colorado, Nebraska, Kansas.	527,000	[d] 94,000	.178	2.41	2,960	300,000	600,000
Big Sioux	Iowa, Minnesota, South Dakota	.....	.....	.....	.....	.....	21,600	38,900
Milk	Montana	.....	.....	.....	.....	.....	30,000	50,000
Marias	do	.....	.....	.....	.....	.....	55,600	75,400
Jefferson	do	.....	.....	.....	.....	.....	317,000	482,000
Madison	do	.....	.....	.....	.....	.....	216,000	276,000
Gallatin	do	.....	.....	.....	.....	.....	94,000	126,000
Minor northern tributaries (Missouri).	Missouri, Iowa, North Dakota, South Dakota, Montana	.....	.....	.....	.....	.....	170,000	230,000
Musselshell	Montana	.....	.....	.....	.....	.....	23,100	26,400
Yellowstone	Montana, Wyoming	.....	.....	.....	.....	.....	1,430,000	2,170,000
Niobrara	South Dakota, Nebraska	.....	.....	.....	.....	.....	122,000	140,000
Platte	Nebraska, Wyoming, Colorado	.....	.....	.....	.....	.....	290,000	657,000
Kansas	Colorado, Nebraska, Kansas	.....	.....	.....	.....	.....	105,000	287,000
Osage	Missouri, Kansas	.....	.....	.....	.....	.....	7,890	19,000
Minor southern tributaries (Missouri).	Missouri, Kansas, Nebraska, South Dakota, North Dakota, Montana.	.....	.....	.....	.....	.....	190,000	360,000
Western tributaries lower Mississippi, below Missouri River (exclusive of Arkansas).	Missouri, Arkansas, Texas, Oklahoma	116,000	102,000	.880	11.90	3,220	.....	.....
Arkansas	Arkansas, Missouri, Kansas, Oklahoma, Colorado, New Mexico, Texas.	177,500	65,500	.369	5.00	2,060	110,000	182,000
Cimarron	Oklahoma, Kansas, New Mexico, Texas	.....	.....	.....	.....	.....	11,500	44,000
Canadian	Oklahoma, Texas, New Mexico	.....	.....	.....	.....	.....	83,900	348,000
Minor tributaries Arkansas	Arkansas, Missouri, Kansas, Oklahoma, Colorado, New Mexico, Texas.	.....	.....	.....	.....	.....	67,000	145,000
Red	Louisiana, Arkansas, Texas, Oklahoma	.....	.....	.....	.....	.....	48,900	148,000
Minor western tributaries lower Mississippi (below Missouri River).	Minnesota, Iowa, Missouri	.....	.....	.....	.....	.....	42,000	126,000
Total		905,200	.....	.....	.....	9,580	3,948,970	7,085,000

[a] Includes all drainage from the Mississippi to Vermilion River, inclusive.
[b] Horsepower at Louisville, Ky.
[c] Includes flow but exclusive of power in Canada.
[d] Mean annual discharge 1879–1890, inclusive, from Annual Report Chief of Engineers, 1891, p. 3826.

Estimate of stream flow and water power in the United States—Continued.

VII. ST. LAWRENCE RIVER.[a]

Stream.	States drained.	Drainage area (square miles).	Flow from area.				Horsepower.	
			Second-feet.	Second-feet per square mile.	Per annum.		Minimum.	Assumed maximum develop-ment.
					Depth in inches.	Billion cubic feet.		
St. Lawrence at Ogdensburg, N. Y.		288,000	252,000	0.876	11.90	7,950		
Lake Superior	Minnesota, Wisconsin, Michigan	76,100	77,300	1.02	13.80		120,000	236,000
Lake Michigan	Michigan, Wisconsin, Illinois, Indiana	68,900	60,500	.878	11.90		246,000	356,000
Lake Huron	Michigan	68,900	60,000	.871	11.80		83,400	110,000
St. Clair	do	214,000	198,000	.926	12.60		3,380	6,760
Lake Erie	Ohio, Pennsylvania, New York, Michigan	[b] 40,800	22,000	[b] .540	7.33		28,000	62,300
Niagara	New York	255,000	220,000	.863	11.70		5,800,000	[c] 6,500,000
Lake Ontario[d]	do	33,000	32,100	.973	13.20		200,000	400,000
Lake Champlain (Richelieu River)	New York, Vermont	7,750	13,500	1.74	23.60	426	102,000	147,000
Minor St. Lawrence tributaries in New York (below Ogdensburg)	New York	3,970	6,550	1.65	22.40	207	99,700	272,000
Total		299,720				8,583	6,682,480	[e] 8,090,060

VIII. COLORADO RIVER.

Colorado River above Yuma, Ariz.	Utah, Nevada, California, Arizona, New Mexico, Colorado, Wyoming.	225,000	16,500	0.0733	1.00	521	1,150,000	2,080,000
Gila	Arizona, New Mexico						72,500	241,000
Little Colorado	do						12,000	24,000
San Juan	Arizona, New Mexico, Utah, Colorado						149,000	341,000
Grand	Colorado, Utah						703,000	1,310,000
Green	Utah, Wyoming, Colorado						812,000	1,510,000
Minor tributaries	Arizona, New Mexico, Utah, Nevada, California						20,000	40,000
Total		225,000				521	2,918,500	5,546,000

IX. SOUTHERN PACIFIC.

Minor streams (southern Pacific)	California	22,800	7,410	0.325	4.42	233	36,400	88,300
San Francisco Bay:								
Sacramento	California, Oregon	31,400	45,500	1.45	19.70	1,430	2,420,000	4,580,000
San Joaquin	California	[g] 16,500	[g] 16,800	[g] 1.02	[g] 13.80	[g] 530	[h] 759,000	[h] 3,140,000
Total		70,700				2,193	3,215,400	7,808,300

X. NORTHERN PACIFIC.[i]

Columbia[j]	Oregon, Idaho, Wyoming, Montana, Washington, Nevada	231,400	312,000	1.35	18.30	9,850	4,060,000	6,250,000
Willamette	Oregon						602,000	1,670,000
Des Chutes	do						953,000	1,920,000
John Day	do						79,700	158,000
Snake	Oregon, Washington, Idaho, Wyoming, Nevada						1,880,000	4,300,000
Spokane	Washington, Idaho						237,000	610,000
Pend Oreille (Clark Fork)	Idaho, Montana						1,530,000	2,620,000
Yakima	Washington						194,000	626,000
Kootenai	Montana, Idaho						207,000	357,000
Minor tributaries, Columbia	Oregon, Washington						718,000	1,230,000
Puget Sound	Washington	14,300	59,200	4.15	56.30	1,870	719,000	1,400,000
Minor streams, Northern Pacific	California, Oregon, Washington	44,700	111,000	2.48	33.60	3,500	1,800,000	3,560,000
Total		290,400				15,220	12,979,700	24,701,000

XI. GREAT BASIN.

Wasatch Mountains drainage	Utah, Wyoming, Idaho	44,300	7,620	0.172	2.33		92,000	149,000
Humboldt	Nevada	25,200	2,420	.096	1.30		20,000	30,000
Sierra Nevada drainage	California, Nevada, Oregon	[h] 55,900	[h] 18,900	[h] .338	[h] 4.58		[k] 396,000	[k] 607,000
Minor streams in Great Basin	California, Nevada, Utah, Oregon	97,600	10,100	1.03	1.40		10,000	15,000
Total		223,000					518,000	801,000

XII. HUDSON BAY.

Red (of the North)[l]	North Dakota, Minnesota	50,000	6,420	0.128	1.74	203	25,000	52,000
St. Mary	Montana	650	1,510	2.31	31.40	48	30,500	120,000
Rainy[m]	Minnesota	11,500	11,500	1.00	13.60	363	20,300	40,600
Total		62,150				614	75,800	212,600

[a] Values of drainage areas and discharge of the Great Lakes drainages derived chiefly from report of E. S. Wheeler, assistant engineer, U. S. Army. The discharge value is given for each of the Great Lakes as a unit from 1860 to 1892, and includes the run-off from both land and water surfaces. It shows the total discharge from both United States and Canadian territory.

[b] Includes Lake St. Clair.

[c] 3,500,000 horsepower at Niagara Falls on the basis of mean annual discharge.

[d] Includes Oswegatchie River and minor St. Lawrence tributaries above Ogdensburg, N. Y.

[e] Total horsepower of Niagara River and of tributaries to the Great Lakes in the United States.

[f] Southern Pacific included between Mexican line and Point Bonita, Cal.

[g] Exclusive of Tulare Lake drainage (see Sierra Nevada drainage).

[h] Includes Tulare Lake drainage.

[i] Northern Pacific included between Point Bonita, Cal., and Canadian line.

[j] Includes drainage area and flow in Canada, but does not include power.

[k] Does not include Tulare Lake drainage (see San Joaquin River).

[l] Includes drainage area and flow of Pembina and Mouse rivers in Canada, but does not include power.

[m] Drainage in United States only.

Estimate of stream flow and water power in the United States—Continued.

GENERAL SUMMARY.

Principal drainages.	Drainage area (square miles).	Flow per annum (billion cubic feet).	Minimum.	Assumed maximum development.
Northern Atlantic to Cape Henry, Va	159,879	8,942	.....	.....
Southern Atlantic to Cape Sable, Fla	123,920	5,560	1,253,000	1,957,800
Eastern Gulf of Mexico to Mississippi River	142,220	6,867	559,000	963,000
Western Gulf of Mexico west of Vermilion River	[a] 433,700	[a] 2,232	433,760	822,650
Mississippi River (tributaries from east)	333,600	12,360	.....	.....
Mississippi River (tributaries from west, including Vermilion River)	905,200	9,580	3,948,970	7,085,000
St. Lawrence River to Canadian line	[b] 299,720	[b] 8,583	6,682,480	8,090,060
Colorado River above Yuma, Ariz	225,000	521	2,918,500	5,546,000
Southern Pacific to Point Bonita, Cal	70,700	2,193	3,215,400	7,808,300
Northern Pacific	290,400	15,220	12,979,700	24,701,000
Great Basin	223,000	.....	518,000	801,000
Hudson Bay	62,150	614	75,800	212,600
Total	3,269,489	72,672	.....	.....

[a] Includes Rio Grande in Mexico.

[b] Includes drainage in Canada.

IRRIGATION.

By F. H. Newell,
Director United States Reclamation Service.

LEGAL STATUS.

The National Government has passed three important laws for the encouragement of irrigation; (*a*) The desert land law, which was best adapted to individual enterprise in the development of comparatively small tracts of land by irrigation systems of moderate size; (*b*) the Carey Act, which was designed to encourage corporate irrigation of public land under state auspices; (*c*) the Reclamation Act, which provides for construction of irrigation works by the National Government itself. Enumeration was made by the United States census of the acreage irrigated in 1889, 1899, and 1902. With those figures as a guide, and by the use of the general information possessed by the Reclamation Service, an estimate has been made of the acreage irrigated in 1907. The results given in the following table include very large areas which receive only one or two irrigations by flood water, and others where the supply is inadequate.

Irrigation in the United States.

NUMBER OF FARMS IRRIGATED.

Year.	United States.	Arid region.	Semiarid region.	Rice region.
1907	[a] 167,200	152,000	7,800	7,400
1902	133,356	122,156	7,021	4,179
1899	110,117	102,819	4,897	2,401
1889	54,136	52,584	1,552	.....

[a] Estimated.

NUMBER OF ACRES IRRIGATED.

1907	[a] 11,000,000	9,700,000	425,000	876,000
1902	9,681,289	8,471,641	405,449	600,199
1899	7,778,904	7,963,273	266,417	251,214
1889	3,631,381	3,564,416	66,965	.....

[a] Estimated.

Irrigation by individual effort has been undertaken in each instance in a small way, but in the aggregate this method has led to the most

important development and has resulted in the largest total acreage. It is also being developed to some extent by corporate enterprise, but results from this source are relatively meager, except where the corporations are of a community character. Cooperative communities have done much in the past and their future works will probably be important. Development by States under the provisions of the Carey Act promises well in some localities where there is efficient state supervision, as in Idaho, Wyoming, and Oregon; large results have already been accomplished in the first-named State. National development through the agency of the Reclamation Act is beginning to show results and is steadily proceeding. It has been confined mainly to those enterprises which are too large, too costly, or too slow in producing returns to tempt private or corporate investments.

The Reclamation Service has 29 projects in various stages of construction; these contemplate the ultimate irrigation of 2,700,000 acres, against a total acreage of 367,023 for which water was furnished in 1908. The following table shows the distribution of the projects, the total ultimate irrigable area under each, and the irrigated areas for 1908 and 1909:

Irrigation projects.

State.	Project.	Irrigable area.	Irrigated 1908.
		Acres.	*Acres.*
Arizona	Salt River	272,000	115,000
California	Orland	14,000	.....
California-Arizona	Yuma	92,000	3,800
Colorado	Grand Valley	62,000	.....
	Uncompahgre	147,000	15,600
Idaho	Minidoka	74,000	24,464
	Payette-Boise	315,000	55,000
Kansas	Garden City	8,500	5,558
Montana	Huntley	28,000	4,400
	St. Mary	.....	.....
	Sun River	256,000	.....
Nebraska-Wyoming	North Platte	164,000	23,220
Nevada	Truckee-Carson	200,000	27,450
New Mexico	Carlsbad	20,000	8,000
	Hondo	10,000	1,500
	Rio Grande	180,000	17,000
North Dakota	Buford-Trenton	12,500	1,200
	Williston	12,000	2,000
North Dakota-Montana	Yellowstone	66,000	.....
Oklahoma	Cimarron	.....	.....
Oregon	Umatilla	20,000	2,500
Oregon-California	Klamath	187,000	9,378
South Dakota	Belle Fourche	100,000	5,000
Utah	Strawberry	60,000	.....
Washington	Okanogan	10,000	1,353
	Sunnyside	90,000	42,000
	Tieton	30,000	.....
	Wapato	120,000	.....
Wyoming	Shoshone	150,000	2,600
		2,700,000	367,023

Under the Carey Act there have been approved 1,716,424 acres for construction, and patents have been granted covering 293,083 acres.

The following table shows the location of the lands being irrigated under this act:

Segregations applied for under the act of August 18, 1894 (28 Stat. L., 372–422), and the acts amendatory thereof, with the action taken thereon, from the passage of the act to July 1, 1908.

[Areas in acres.]

State.	Selected.	Rejected, relinquished, etc.	Approved, not patented.	Approved and patented.
Colorado	59,807.94	5,704.95	54,102.99	.....
Idaho	1,180,566.17	265,828.94	662,254.00	156,954.90
Montana	104,587.98	2,792.53	83,498.54	18,296.91
Nevada	12,644.61	8,000.00	.....	.....
Oregon	432,202.53	78,507.31	245,287.52	50,063.13
Utah	328,327.40	236,980.83	48,226.74	.....
Washington	155,649.39	155,649.39	.....	.....
Wyoming	965,598.64	198,994.18	623,054.44	67,768.72
Total	3,239,384.66	952,458.13	1,716,424.23	293,083.66

Oregon segregation list No. 5, covering 58,344.57 acres, is now pending before the Secretary on appeal from the decision of the General Land Office rejecting it.

Wyoming segregation list No. 27, covering 26,936.03 acres, was rejected by the General Land Office, which decision was affirmed by the department, but said decision has not yet become final.

Irrigation under the Indian Service is rapidly increasing.

The extent to which the irrigated area in the arid and semiarid regions can be increased can not be accurately estimated with present knowledge. If all the run-off waters of the arid region could be conserved and employed in irrigation, the total area might, perhaps, be brought to nearly 60,000,000 acres. This is very uncertain, however, as our knowledge of run-off is confined to only a portion of the streams, and is incomplete; furthermore, such an estimate involves assumptions regarding the duty of water that may introduce large errors.

It is known, however, that large portions of the water of the arid region can not be used in irrigation, as no irrigable land exists upon which it can be brought at feasible cost. In general, it may be stated that the value of irrigated land is increasing, and certain developments are tending to decrease costs of construction, so that it is impossible to draw any approximate line of demarkation, even if we had full knowledge regarding present costs. This would require elaborate surveys, which have not been made. For these reasons any present estimate of the total irrigable area would necessarily be little better than a guess. With present data, the closest statement is probably between 40,000,000 and 50,000,000 acres, including that now under ditch.

The subjects of irrigation, forestry, navigation, power, domestic water supply, and drainage are all closely interrelated and should be thoroughly studied together, not only in the arid but in the humid regions. No one of these questions can be properly treated without full regard to all the others. Proper study of these comprehensive

questions should include more extended observations of rainfall and evaporation, especially in high altitudes, and of the annual flow of all streams. Comprehensive topographic maps should be made showing the areas of drainage basins, the location of reservoir sites, and their relation in altitude and location to irrigable lands and to power and navigation resources. Such maps are the basic information most urgently needed for all land classification, and without them no wise policy can be adopted.

WATER LAWS.

Both state and national laws are incomplete in permitting and encouraging the settlement and improvement of lands which should be reserved for reservoir sites. Thorough surveys should be made and all feasible reservoir sites discovered and reserved for development.

The present laws in some States tend to promote irrigation, but in others they do not. The most primitive form of regulation of the use of water in irrigation is best exemplified by the present laws of the State of California. These declare the principles of priority and beneficial use, and provide that claims to the use of water shall be recorded in the form of a notice of appropriation, and shall be perfected by application to a beneficial use. At the same time they try to recognize as concurrent on the same stream rights derived by prior appropriation and rights depending on riparian ownership. The riparian doctrine of water rights should be definitely and permanently abrogated in all arid regions. This has been done in some States by constitutional provision and in some by judicial decision. In all the States of the arid region where the riparian doctrine is recognized, material modifications in the old common-law doctrine have been made and put into effect.

The form and theory of these laws have been developed by several of the States, elaborating upon the principles of the California laws and the methods established in that State.

The operation of the earlier forms of these laws places no restraint upon appropriations of water. The courts in passing upon the claims of the appropriators, having scant information concerning the amount of water available for use, with no guide to the quantities which should be applied in the cultivation of crops, and confronted with the excessive claims of the parties, have often adjudicated rights to the use of water many times in excess of the amount carried by the stream.

The knowledge obtained during recent years concerning the discharge of streams and the use of water has caused such decrees to become exceptional in present practice. Nevertheless, the need for a more careful regulation of the appropriation and use of water has been apparent for many years.

In 1890 the State of Wyoming enacted a code of water laws providing for supervision of the utilization of the water supply through a state engineer and state board of control who adjudicate rights to the use of water in the first instance. The division superintendents and water masters have immediate charge of the distribution of the water in the various water divisions.

Nebraska subsequently adopted a code of water laws similar to the laws of Wyoming.

Idaho, Utah, and Nevada in 1903 adopted codes of water laws based upon those of Wyoming with, however, a number of important modifications dictated by experience and the development of irrigation practice.

At the sessions of the legislatures of Oregon and Washington in 1903, the governors were directed to appoint commissions to prepare and submit drafts of a code of irrigation law.

At a joint session of the two commissions with the then chief engineer and other members of the Reclamation Service held in August, 1904, the fundamental principles of a modern irrigation code were discussed. There was also some consideration of the provisions which should be incorporated in such a code to facilitate the operations of the Federal Government in carrying on the work of constructing the irrigation systems contemplated by the act of Congress approved June 17, 1902 (32 Stat., 388), known as the Reclamation Act.

After this meeting, a state code of water laws was drafted by Mr. Morris Bien, supervising engineer of the United States Reclamation Service, which, in 1905, was adopted without material change by the legislatures of North Dakota, South Dakota, and Oklahoma. The legislatures of Oregon, Washington, and New Mexico adopted parts of this code, but omitted some of the most important features. This code does not involve any new principles, but constitutes a revision and combination of the features of the more modern statutes, arranged as a consistent and complete code.

PROPOSED WATER CODE.

A state code of water laws should provide for the appropriation, adjudication, and apportionment of the waters of the State, and divides itself naturally into four branches.

First. A declaration of the fundamental principles upon which the right to use water shall be based.

Second. The adjudication of rights to the use of water claimed under the previous laws, thus determining the unappropriated public waters.

Third. The regulation, control, and determination of the rights to water to be subsequently acquired.

Fourth. The regulation and control of the distribution of water, rights to the use of which have been established.

The code under discussion is arranged to provide appropriate procedure for the application of these principles.

Under the first heading the fundamental principles are few and well established, namely, that all the waters within the limits of the State belong to the public and are subject to appropriation for beneficial use, except from sources of supply which are navigable; that the prior appropriation of water shall be the basis, and beneficial use the measure and the limit of the right; that the use of water is a public use, and private parties may exercise the right of eminent domain for the utilization thereof; and that water used for irrigation shall be appurtenant to the land on which it is used.

Under the second heading, providing for the adjudication of rights claimed under prior laws, it is now generally conceded that the final adjudication must be by the courts. The codes of the different States contemplate various forms of procedure. In the code referred to, a state engineer, appointed for six years by the governor subject to confirmation by the Senate, is to make a complete hydrographic survey of a stream system, obtaining all the data necessary to determine the amount of water available and the rights of the parties entitled to the use of it. This material is turned over to the attorney-general of the State, who is required to enter suit promptly for the determination of the rights of all parties and to prosecute the same diligently to a conclusion. In all suits for the determination of the right to the use of the waters of any stream system, all who claim the right to use such waters shall be made parties. In all suits involving the determination of water rights, the attorney-general is required to intervene on behalf of the State, if in the opinion of the state engineer the public interest requires it.

The third subject, namely, that of the regulation, control, and determination of rights to the use of water to be acquired, is placed in the hands of the state engineer. The procedure proposed is substantially the same as that adopted in the other States having a modern irrigation code with some differences of detail.

The principal feature to be noticed is that before any work looking to the construction of an irrigable system is commenced, and after the state engineer has passed upon the form and substance of the application, the intention to appropriate the water shall be published in a newspaper circulated in the community. After such publication the state engineer will approve the application if no valid objection is presented.

When the construction is completed, the works are to be inspected and approved by the state engineer, who will then determine their capacity, which will limit the amount of the appropriation. Afterwards when the water is applied to a beneficial use, the state engineer

makes a further inspection, whereupon he issues a license for the appropriation of the amount of water which has been applied to a beneficial use. A time limit is fixed for completion of construction and for beneficial use.

For the distribution of the water, which comes under the fourth branch, the States are divided by the law into water divisions by drainage areas, each under the supervision of a water commissioner appointed by the supreme court of the State. Their function being the distribution of water under judicial decree or appropriation, they may be regarded as, in a sense, officers of the court. The water commissioners with the state engineer constitute a board of water commissioners, of which the latter is president. The water commissioners each serve six years, their terms being so arranged that a new one is appointed every two years. This board has general supervision over the waters of the State.

The actual work of distributing the waters to those entitled to use them is performed by water masters appointed by the water commissioners with the approval of the state engineer. Each water master has charge of a water district set apart by the state engineer, as found necessary from time to time. The operations of the water master are under the supervision of the water commissioner, and their acts are subject to appeal to the state engineer.

The cost of the water distribution is borne by the water users. The general expenses of the state engineer and the water commissioners are paid by the State. The greater part, if not all, of this expense will be returned to the state treasury by the fees collected by the state engineer and by the repayment of the cost of hydrographic surveys by the parties to the suits for adjudication.

Special reference should also be made to the features of the draft relating to the work under the federal Reclamation Act.

In order that the State may obtain the full benefit of this work and to prevent serious interference with, and perhaps the entire abandonment of, the projects which are considered for investigation, it is provided that the water supply for such projects shall be reserved from general appropriation until the investigations of the Reclamation Service shall determine the precise amount required for the project, the remainder being then released from such reservation.

It is also provided that state lands coming under such project shall be disposed of in harmony with the plans for the disposition of the lands of the United States, and that lands required for the reclamation project for irrigation works shall be transferred to the United States without charge.

In all sales of state lands after the enactment of the code, the conveyance is to reserve right of way for ditches or canals constructed by authority of the United States.

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The theory of these provisions is that the State regulates the appropriation of the water, exercising this power and holding the land in trust for the public, and when the interests of the public are so directly involved as in these large irrigation projects, and when, further, there is no element of individual speculation or profit in the construction of the works, which are for the purpose of establishing the maximum number of homes on the land, it is the duty of every State to which the Reclamation Act is applicable to assist with every resource under its control.

It will be of interest to review several of the other provisions of the draft.

Units of measurement are established; the cubic foot per second for the flow of water and the acre-foot for volume. The miner's inch is fixed as one-fiftieth of a cubic foot per second, unless a different ratio has been agreed upon by contract or established by actual measurement or use. The miner's inch has been used in some States as a unit, but it is unsatisfactory, because it is not easily defined with exactness.

The amount of water which may be appropriated for irrigation is limited to 1 cubic foot per second for 70 acres or its equivalent.

While it is conceded that water used for irrigation must be appurtenant to the land, the fact should be recognized that conditions may arise to make it impracticable or uneconomical to continue to irrigate a particular tract. Provision is made so that the use of water may be severed from the land after application to the state engineer, due publication of notice of such intention, and approval by the state engineer. Similar provision is made for a change in the nature of the use to which the water is applied, or in the place of diversion, storage, or use.

The subject of seepage water is one that has given much trouble, and provision is made for the appropriation thereof in the same manner as other waters, with the requirement that the appropriator must pay reasonable charges for storage or carriage to the owners of the irrigation works from which it comes, provided that the seepage can be traced to such works beyond reasonable doubt.

All decisions of the state engineer or water commissioners affecting a substantial right are subject to appeal to the courts.

RECENT STATE LAWS.

In the session of 1907 the Montana legislature considered a draft of a code prepared by a commission appointed by the governor which followed substantially the code referred to, but it was not adopted. The same is true with the legislature of Oregon.

During the year 1908 there has been a general movement toward the preparation of a code substantially in the form considered in

the State of Oregon, and it is probable that it will be strongly urged upon the legislature early next year.

In many of the States statutes have been adopted tending toward the system discussed, and as this procedure is gradually enforced and modified as may be found advisable after experience, those States in which such laws have been enacted will do much toward the proper promotion of the irrigation industry.

It is generally conceded that those States in which statutes of this kind are not in force can best assist in the development of irrigation by following the principles and procedure there indicated.

One important feature of the law of irrigation has thus far received no attention in legislation, namely, the regulation of interstate waters. The decision of the United States Supreme Court in the Kansas-Colorado case (206 U. S., 46) and the decisions of some of the district courts of the United States in other cases, together with some decisions by state courts, have shown a tendency to consider this question, but in no case has there been an announcement of a principle which tends to meet the complicated conditions.

All the cases concerning interstate waters have involved only specific rights of the litigants; nothing has yet been accomplished outlining the method of providing for an adjudication of the waters of an interstate stream in such manner as to determine all the rights involved.

The principal difficulties arise from the fact that suit may be brought by one party against another and a decision obtained, which would not, however, bind anyone who is not party to the suit, and the complications in judicial procedure are such as to make it difficult, if not impracticable, under present conditions and rulings to bring into consideration in any one case all rights on interstate streams in two or more States and so arrange that one adjudication shall determine the rights of each party as against all other users of water from that stream.

Whether this matter can be adjusted by the courts themselves without the assistance of legislation or whether legislation is absolutely necessary has not yet been demonstrated.

It has been proposed by some that Congress should provide for a tribunal empowered to investigate claims to the use of water of interstate streams and to prepare reports upon all facts affecting priorities and the use of water, the same to be submitted to the federal courts for adjudication, following in general the procedure outlined in the proposed code in regard to the adjustment of water rights within the State.

UNDERGROUND WATERS.

By W. C. Mendenhall.

INTRODUCTION.

Underground waters constitute one of the three natural subdivisions of precipitation. These subdivisions are evaporation, surface run-off, and percolation. That part of the precipitation which passes below the soil surface by seepage into the soil pores becomes thereby a part of the body of underground waters. Eventually it is returned to the air to begin again its circuit through the air and back to earth. This return to the air may be accomplished very quickly or very slowly. Capillarity and evaporation may withdraw the earth moisture and return it to the atmosphere before it has reached any considerable depth in the soil mantle, or it may pass beyond the reach of these forces and begin a journey through the soil pores or the rock masses that may continue for a few hundred feet or a few hundred miles. The waters may even accumulate in a porous rock mass and may remain there stored and practically motionless for centuries or for geologic epochs. All of that portion of the precipitation that is absorbed and remains underground for either a long or a short period, following a long or a short course, constitutes the ground water. There is, in addition, a certain amount of original water, either magmatic or included with the sediments at the time of their deposition. The aggregate quantity of this is undoubtedly very great, but as it is in general inaccessible to man, little attention need be given it in a discussion of water as a resource.

An estimate of the quantity of surface waters is a large but a relatively simple problem. It can be solved by the patient application through long periods of well-determined engineering methods. The resulting estimates, since they are those of the engineer and the mathematician, are correct within a limited percentage of error, because all the factors of the problem are capable of close determination. But although the quantity of surface waters is measurable, its maximum possible use is not rigidly determinable, because that problem contains a number of variable factors. Man's mastery over the mechanic arts is constantly increasing. That which is impossible to him to-day becomes possible to-morrow. Furthermore, economic

controls are constantly shifting. A water power that is not available this year, not because of unsolved mechanical problems, but because of cost, may be easily available next year, because a railroad has been built, or a mine has been opened, or population has shifted. These are things that neither the mathematician nor the economist can predict. They introduce into the problem of determining the possible future use of any resource a factor so variable that the result is of doubtful value. Suggestions only can be made; rigid determinations are not possible.

As to ground waters, neither the determination of the total quantity nor of the maximum use is capable of close solution. The first involves general estimates of factors not directly measurable, such as the percentage of pore space in deeply buried and inaccessible material, soils, and rocks. These estimates must be made by the deductions of an inexact science, geology, instead of through the measurements of an exact science, engineering. The same variables enter into the determination of the maximum possible use of ground waters as into the maximum possible use of surface waters, namely, different and constantly shifting economic controls. It may be highly profitable to pump ground waters 500 feet vertically for the irrigation of citrus lands in southern California whose product is worth $250 per acre per year, whereas it may not be possible to pump 50 feet vertically in another locality, where the products are not worth $10 per acre per year. Notwithstanding, some such crude estimate as may be made of the quantity of these resources is helpful, since it gives us a concrete conception of the amounts with which we are dealing.

QUANTITY.

Estimates that vary widely have been made as to the total amount of this ground water. These estimates range from an amount sufficient to cover the earth to a depth of 96 feet (Fuller) to an amount sufficient to cover it to a depth of 7,500 feet (Delesse). The lower estimate is the later and may be regarded as of the greater value. The determination of the total quantity of underground water in existence, however, while a question of scientific interest, is of no practical moment, since only a very small proportion of the total is accessible to man and can therefore be made use of by him. And again, of the relatively small amount that is within reach, only that proportion that, if withdrawn, will be restored annually can be utilized, because, obviously, withdrawals in excess of this mean reduction of the principal and eventual bankruptcy.

Hence, although impressive estimates of the total may be made—as, for instance, the statement that there are 600 cubic miles of potable

ground waters beneath the State of Florida, 800 cubic miles in the Great Central Valley of California, 1,000 cubic miles in the Dakota sandstone aquifer, and 10,000 cubic miles in the sediments of the Atlantic and Gulf coastal plains—these statements are not merely valueless, they are sadly misleading, because, if issued without explanation, the inference would follow that such a tremendous amount of water could be extracted from these districts and used by man. This inference is wholly unjustified for a number of reasons. In the first place, only a limited although variable percentage of the water that saturates those parts of the rock or soil masses that are within reach of pumps can be extracted in development; the remainder, much the larger proportion, being capillary and subcapillary, is not capable of extraction in any commercial way.

Again, these estimates of total ground waters include those at great depth, utterly beyond the reach of any pumps or known devices for their recovery. And, finally, of the very small proportion of the total that can be brought to the surface and made useful to man, only an amount should be taken out that is equal to the annual restorations; otherwise there will be a gradual depletion of the supply and a corresponding increase in the cost of the product. Hence, as a practical people, we are not in the least concerned with the total quantity of ground waters, but only with the possible annual accessions to the total, for this controls use.

USE.

The use of ground waters in a limited way for domestic and farm supplies is well-nigh universal. Municipal use, although not so general, is also extensive; whereas use for irrigation, confined, of course, to the arid and semiarid States, has begun to attract attention only since power development, either by the utilization of the energy of running water or by means of small power plants of the steam or internal combustion type, has become general. With the imperfect data at hand it is not possible to estimate the total volume of ground waters now used throughout the United States, but it is believed that in Florida at least 2,000 second-feet are developed and in California more than one-half as much. The development in these two States, therefore, representing as they do more than the average development in the East and the West, is about 3,000 second-feet. Florida and California include about 7 per cent of the area of the United States. If the development throughout our domain can be regarded as on the average one-half as intense as in these two States, the total ground waters used if united in one stream would equal twice the volume of the Potomac at Point of Rocks, Md., in 1903, with a drainage area of 9,650 square miles, or if a smaller factor

is used and the average intensity of development be regarded as one-third that of the two States named, we reach the conclusion that the ground waters now in use would make a river the size of the Colorado at Yuma, Ariz., with a drainage area of 225,000 square miles. Expressed in still another way, this volume is equal to somewhat less than 1 per cent of the total stream flow in the United States. It is to be clearly understood that this represents only artificial development, a direct product of man's activity, and does not include the natural springs which represent the unassisted return of ground waters to the surface. To these is due a very large although undetermined proportion of the low-water flow of all our streams.

PRESENT TENDENCIES.

One of the late phases of the irrigation movement involves the use of ground waters for this purpose. This movement has been inspired by the success of certain communities that have developed such waters and reclaimed a large acreage by their use. The southern California communities, one-half of whose irrigation is accomplished in this way, illustrate what can be done. In the San Joaquin Valley development of this type is under way and will inevitably be greatly extended. Three hundred second-feet of ground waters are now used there; probably 3,000 second-feet are available, and colonies are being continually established and individual settlers are constantly entering the valley who are reclaiming more and more acreage by the use of this resource. In other western valleys, as in Utah and in Arizona, development of the same type is under way. Among the famous ground-water districts is that of the Great Plains, east of the Rocky Mountains, underlain by the Dakota sandstone, that yields some of the largest flowing wells of the United States. Another important district includes parts of Minnesota, Iowa, and Wisconsin, beneath whose surface lie water-bearing beds older than the Dakota sandstone, but the beds are locally quite as important. In these latter States irrigation is not practiced, but the ground waters are of great importance as sources of domestic and municipal supplies. In the Eastern and Southern States, those of the Atlantic and Gulf coastal plains are most favorably situated in regard to their ground-water supplies and in them development is more intense than elsewhere in the East. Attention has already been called to Florida, in which nearly 2,000 second-feet of ground waters are developed, nearly one-half of this amount being used for irrigation and domestic purposes. Mississippi, Louisiana, and Texas have abundant underground supplies extensively drawn upon in certain localities, but capable of much more extensive use. Data are not at hand for estimating the amount withdrawn at present.

WASTE.

Attention is usually first centered upon the use of ground waters by the development of flowing wells in areas where they may be secured. The advantages of a supply of this type are many. The waters usually cost little, they are protected from contamination, the output is regular, at least until development becomes too intense for the supply, and the quality is constant. But in regions in which flowing waters are used for irrigation and may be procured at shallow depths the resource is often shamelessly wasted. More wells are drilled than are needed and the water is used during but a small portion of the year, but is nevertheless allowed to flow with consequent reduction of head and depletion of supply and often in addition direct damage to the lands upon which it wastes. This waste is not so serious in humid regions in which the loss is quickly replaced by rainfall, but it goes on with equal recklessness in arid and semiarid sections in which the damage is irreparable. This waste is often in direct violation of state statutes, framed especially to prevent it. Where ground waters do not flow out upon the surface but are developed by pumping, waste does not take place, since the cost of production regulates automatically the amount of water withdrawn. Irrigation practice under these conditions is always superior, as the water user, paying for each gallon that he applies to his land, reduces this amount to the lowest effective quantity in order to save cost. Hence almost invariably better results are obtained with a lower duty in districts where irrigation water must be pumped than in those in which it flows.

In the humid regions ground waters—almost everywhere available—are particularly useful as sources of farm, domestic, and municipal supplies and for certain industrial purposes. They are especially beneficial and of particularly good quality in the coastal plain of the Atlantic and Gulf States and in the glaciated regions where the mantle of drift or of unconsolidated sediments forms a reservoir of great capacity, whose supply is rapidly renewed when drawn upon because of the abundant rainfall. Outside the coastal plain and the drift-covered areas conditions are variable, but generally they are inferior to those in the regions named, because the soil mantle over the rocks is often thin and irregularly distributed and in addition is frequently clayey and of small holding capacity. Within either of these regions there may occur synclinal basins of porous rock like the St. Peter sandstone and associated beds in Minnesota or the Dakota sandstone in the Great Plains, both of which form most important reservoirs. Usually, also, the fractured upper surface of whatever rock lies immediately below the soil carries a supply that may be drawn upon by town and farm wells.

IMPORTANCE.

The importance of these supplies in humid regions to the dwellers there is illustrated by Mr. Frank Leverett's careful determination of the fact that 75 per cent of the population in Michigan are directly dependent for water upon the underground supply, and since the constancy of the lakes and the flow of the streams upon which the remaining 25 per cent depend is also related to the ground waters, the importance of these is really greater than the given percentage indicates. A recent investigation of 19 counties in north-central Indiana again indicates the vital relation that ground water bears to daily life. Of 54 communities in these 19 counties having public supplies, 45 use wells alone and 3 others use both streams and wells. The urban population is therefore largely dependent upon the subsurface supplies and the rural population depends almost entirely upon them. It is estimated that in Florida 750,000,000 gallons of ground waters are used daily for town and country domestic supplies, while an additional 11,500,000 gallons are used by the cities and 500,000,000 gallons for the irrigation of tobacco, citrus fruits, and vegetables. One-half of the irrigation and the greater part of the city supplies in southern California, amounting to more than 300,000,000 gallons daily, are drawn from the sands and gravels that underlie the valleys, while in central California a smaller but nevertheless important draft is made upon the same source.

These available facts, selected from widely scattered localities, indicate clearly that in addition to the almost universal dependence of the rural population upon underground waters for culinary and domestic purposes, an important and growing use is made of them for irrigation and for town supplies. It is probable that it would be safe to apply percentages but slightly less than that determined in the State of Michigan to the entire United States, and to state that nearly 75 per cent of our population depends directly upon underground waters.

RELATION TO STREAM FLOW.

The indirect dependence of mankind upon ground waters is difficult to determine. The greater part of the low-water flow of those of our streams that have no large lakes, swamps, or glaciers in their drainage basins is sustained by the slow escape from soil and rock and vegetable mulch of water that is stored there during rains and the melting of snow. An amount equivalent to the low-water flow is also contributed of course during high-water periods, so that only that part of the annual run-off of ordinary streams that is represented by the excess of flood flow over low-water flow is discharged directly from the surface, without joining the body of the percolating waters.

The remainder, for a longer or shorter part of its journey from the clouds to the sea, has been stored underground and the rate of its seaward passage thereby notably checked. The greater the proportion of precipitation within a drainage basin that joins the underflow, therefore, the more regular the streams of that basin. Areas of little or no underground storage are areas of violent floods and extreme droughts, while areas with a large proportion of underground storage are areas of slight floods and large and well-sustained low-water flow. Hence as a national policy all should be done that can be done to increase underground storage.

The factors that affect it favorably or adversely are many, and too few of them are within the control of man. Hence those that he can control should be used to the best possible advantage. Among these controlling factors are the character of the precipitation, the topography, including the steepness of slopes and of stream channels, the geology—that is, the character of the rocks and the soils—and finally the vegetation.

If the precipitation is violent and is concentrated within a short period, much less opportunity is afforded for its absorption than if the rain falls gently for a longer period. Brief violent storms are characteristic of our deserts where destructive floods are followed by long-continued droughts.

The effect of the topographic character of a drainage basin is obvious. There will be relatively little run-off from a perfect plain if the rocks or soil beneath it have absorptive capacity. In a region of steep slopes and stream channels of high gradient, on the contrary, water does not stand, and a comparatively slight precipitation will be followed promptly by a notable run-off, unless other favorable factors serve to prevent it.

The influence exerted by geology is also a powerful one. The type of rock, the presence and depth or the absence of soils derived from it, and the existence of a mantle of glacial drift often make the difference between a region well supplied with ground waters and drained by streams of regular flow and a region without ground waters and with most erratic and uncontrollable streams. Loose sandstones absorb water like sponges, to yield it slowly at some lower point, perhaps in a distant drainage basin. Cavernous limestones may offer tortuous underground passages through which water escapes slowly; the loose heaps of glacial débris permit but little surface escape, so thoroughly do they absorb the water that falls upon them. The deep mantle of decayed rock that covers many of our Southern States is equally effective in this respect. Polished glacial surfaces, on the contrary, such as exist in parts of the Sierra, shed water as effectively and promptly as a roof. Dense slates, fresh

and unfractured granites, or close-grained metamorphic rocks absorb little or no water and contribute practically nothing to the underground supply.

Finally, the various cover growths are of the utmost importance in modifying absorption and run-off. Trees, brush, grasses, and growing crops act in many ways to this end. Everywhere the roots, penetrating the soil and decaying there, leave little channels for the circulation of the water; on mountain slopes and rocky areas they hold loose fragments of rock by their binding root systems and prevent them from being washed away so soon. The crevices about the rock fragments which are thus held become little storage reservoirs. The trees aid in making these crevices by the prying action of their roots and by the disintegrating action of the vegetable acids that are yielded by their decay. The various growths build up a porous absorptive soil by the litter which they shed and the rock sand which becomes enmeshed in their roots, and they protect the soil which thus accumulates and prevent it being swept away. Finally, they interfere directly with run-off by the obstacles which their roots, stems, and fallen leaves and branches offer to the flow of water over the surface. In all of these functions the immediate escape of rains as sudden floods is checked and their absorption, to be slowly released later, is encouraged. It is because of the full recognition of this part that forests play in the conservation of ground waters and the regulation of run-off that engineers and geologists who have made a special study of ground-water supplies and their relation to surface waters are such earnest advocates of the conservation and extension of forest cover.

LIMITATIONS AND METHODS.

Something has been said of the wide extent of ground waters, of their enormous aggregate volume, of the direct dependence of man upon them, of their critical relation to the more obvious stream flow, and of the growing recognition of their latent value and industrial possibilities. A word should be added as to the danger of exaggerating their utility or their practical quantity in some places and the complex problems involved in their utilization.

They are ultimately dependent upon rainfall. Therefore, like surface waters, they are less abundant in arid than in humid regions, and when used there they will be less rapidly renewed. But because of the greater need more attention is paid to them in the dry than in the wet States; they are more vigorously developed there and there is more danger that they may be overdrawn.

Many gravel-filled valleys west of the Rocky Mountains contain both surface and underground waters, not enough of either alone to irrigate all of the tillable lands, but when both are used together

much more valuable than when either is used alone. Often power can be developed upon surface streams and this power applied to the recovery of the earth waters that saturate the lower valley lands. This mountain water coming down to the lands from above is made to lift the underground water to the lands from below—a most admirable combination and one excellently illustrated in the case of the Santa Ana River in southern California.

A part of the water of this river is stored in a reservoir in the San Bernardino Mountains and the flow of the stream thereby regulated. After it escapes from the reservoir it is diverted through a power plant and electric power is generated. Below the first power plant it is rediverted and passed through a second power plant. Below this it is all distributed and used for municipal and irrigation purposes about Redlands and Highlands. The waters that return from the irrigation are recovered in springs and flowing wells and by pumping plants, a portion of the power developed higher up on the stream being used for the latter purpose. This recovered water is used for irrigation about San Bernardino and Riverside. A part of it reappears in the river above Riverside Narrows, where it is again taken out into a power ditch whose waters are returned to the river above Corona. A few miles below it is picked up by canals and distributed to the orange and deciduous groves about Anaheim and Santa Ana. The portion of it that returns there, by irrigation, to the ground water is once more recovered by the many pumping plants and flowing wells west of Santa Ana in the lower coastal plain.

A single drop of water in its progress from the mountains to the sea, a distance of only 100 miles, may thus be used as many as eight times for power and irrigation. This is an almost ideal use of water. The combination of power development and the recovery of underground waters to supplement the surface flow results in a minimum of waste and a maximum of economy. Development of this type is being rapidly extended now over parts of the West and will receive still further extension in the future.

But care must always be taken not to tax too severely the underground basins from which the water is drawn. They are not by any means inexhaustible. When rainfall is light, the quantity of water returned to the reservoirs each year may be small, although the quantity stored there is large. However large it may be, if more is withdrawn each year than is replaced, there will be gradual lowering of the ground-water level and ultimate disaster. Therefore, users of ground waters in arid regions must study carefully the effects of development in order to be sure that they are not prospering during the present at the expense of disaster in the future. Furthermore, in many sections where water is badly needed ground waters do not

exist. Residents of such sections, urged on by their need, do not always realize this, and attempts that are hopeless from the beginning are made to procure them. Each field is a particular problem with its own solution. General rules have only a limited application.

RELATIONS TO OTHER RESOURCES AND TO CONSERVATION.

Ground waters and surface waters are, of course, intimately related. All usable ground waters were first surface waters, although perhaps only momentarily, and the greater part of them eventually become surface waters again after their journey underground is completed. It is thus that they sustain stream flow during dry periods and so are closely related to power development and to irrigation, both of which are much more successful with a sustained and regular than with an erratic run-off.

Practically all vegetable life depends upon the existence of ground water. It sustains our crops and our forests and is in turn protected by them through functions already outlined. Seventy-five per cent of our population depends directly upon it, and an important additional percentage indirectly. It is used in irrigation, in industry, in transportation, in all the many activities of life. But, being one of the resources that is constantly renewed by natural processes, we need only exercise reasonable care in our use of it to have it to draw upon perpetually. There are districts in the United States, fortunately few in number and small in area, where the ground waters are being extracted faster than they are renewed. There are other areas in which they are being contaminated and rendered useless or harmful by the careless discharge of industrial waste or sewage or brines from deep wells. There are still other areas in which, through the stripping of the natural cover growths, the annual accessions to the supply are materially reduced. These conditions must be met and remedied; then nature, through her annual rainfall, will repair the harm, as yet slight, that has been done.

DENUDATION.

By R. B. Dole and H. Stabler.

INTRODUCTION.

The accompanying tables present estimates of the rate of denudation in the United States. The figures show the rate at which the earth's crust is being moved as solid particles carried in suspension by streams and as matter carried in aqueous solution. The first table is a summary of the estimated denudation for the whole United States and for the primary drainage basins; the other tables contain detailed estimates for smaller areas. The map indicates graphically the rates of denudation in different parts of the country.

SOURCES OF DATA.

The computations of denudation factors are based on figures representing the amount of mineral matter carried by streams, the size of the areas tributary to the streams, and the quantity of water discharged by the streams. The run-off data are derived principally from measurements made by the water-resources branch of the United States Geological Survey; some of the measurements, especially in lower Mississippi Valley and on the Great Lakes, were made by the Engineer Corps, U. S. Army; the Weather Bureau, Department of Agriculture, has contributed series of gage heights in several streams; and estimates of run-off based on the best available information have been made for areas regarding which no measurements are at hand. The estimates of the size of the drainage basins are either copied from printed reports or measured from the best available maps. The greater part of the chemical data are derived from complete mineral analyses of river waters, about 5,000 in all, performed for the water-resources branch under the direction of R. B. Dole by W. M. Barr, F. W. Bushong, C. K. Calvert, W. D. Collins, F. M. Eaton, J. R. Evans, P. L. McCreary, Chase Palmer, J. L. Porter, M. G. Roberts, F. C. Robinson, Walton Van Winkle, and A. J. Weith. Daily samples of water were collected for one year from about 150 rivers and lakes in California and in the States east of the one hundredth meridian. Ten consecutive samples were

then united and the composites thus obtained were subjected to complete mineral analysis. The information regarding dissolved and suspended matter in the streams of the arid States, except California, has been furnished by the United States Reclamation Service from work done under the direction of W. H. Heileman, but unfortunately the detailed analyses could not be procured and therefore the comparative accuracy of the estimates is unknown. In the California and the Reclamation Service work 50 cubic centimeters of filtered and 50 cubic centimeters of unfiltered sample were evaporated, dried at 110° C., and weighed to determine suspended and dissolved solids. In the other analyses the suspended matter in 500 cubic centimeters of the sample was removed by filtration through a Gooch crucible, dried at 180° C., and weighed for suspended solids; the filtrate was then evaporated, dried at 180° C., and weighed for dissolved solids. Some error is introduced by comparing solids determined at 180° with solids determined at 110°. The size of the error varies with the amount of organic matter and water of crystallization present and with the character of the solids themselves, and is probably variable for different rivers and for the same river from time to time; consequently no correction for it has been made. In most cases, however, this circumstance introduces less than 10 per cent error.

The figures for Kennebec River are computed from analyses by G. C. Whipple and E. C. Levy. The dissolved solids for Connecticut River and for Housatonic River are from reports of the Connecticut state board of health; for Merrimac River, from reports of the Massachusetts state board of health; for Blackstone River, from reports of the Rhode Island state board of health. The data for Hudson River at Albany, N. Y.; Potomac River at Great Falls, Md.; and Allegheny River at Pittsburg, Pa., are from reports of water-supply investigations at those places. The figures for Colorado River at Yuma, Ariz., are computed from analyses by R. H. Forbes and from others made in continuation of his work by the Reclamation Service. The data for Ohio River at Louisville, Ky., and at Cincinnati, Ohio, are quoted from reports by G. W. Fuller. The data at West Alton and at Jefferson Barracks, Mo., are quoted from analyses by A. W. Palmer in connection with the case of the State of Missouri against the State of Illinois and the sanitary district of Chicago. The estimates of suspended and dissolved solids at New Orleans, La., are computed from fifteen years' sediment determinations by the Engineer Corps, U. S. Army, and from five years' determinations by the New Orleans water and sewerage board. In all the quoted analyses the estimates are given by weight and not by volume, and in nearly all cases they show the average condition of the water for one or more years.

METHODS OF COMPUTATION.

The estimates of denudation, computed from the above-mentioned data by H. Stabler, indicate the removal in solution and suspension of solids from the primary and secondary drainage basins of the United States as classified by the Geological Survey. The determinations on which the computations are based are given in detail. The eleven primary basins are designated by Roman numerals. Under the secondary basins, which are designated by Arabic figures, important tributaries and the sampling stations are indicated.

The second, third, fourth, and fifth columns of the tables give, respectively, the areas of the basins, the dissolved solids, the suspended solids, and the annual run-off per square mile. In columns 6 and 7 the annual denudation in tons per square mile for the areas above the points at which samples were collected is computed by multiplying together solids in parts per 1,000,000, run-off in second-feet per square mile, and 0.985; in all other regions the denudation is estimated from the data for known areas. Columns 8 and 9 show the total denudation in thousands of tons per year, computed for the secondary areas by multiplying denudation in tons per square mile per year by the drainage area in thousands of square miles.

The depth in millionths of an inch per year covered by the material removed is found by dividing the tons per square mile per year by 0.1917 and the last three columns bear reciprocal relations to columns 10, 11, and their sum. Any attempt to estimate erosion in volumetric terms from determinations of dry suspended matter and dissolved solids involves the use of factors which are by no means absolute. The actual specific gravity of the mineral substance carried in streams in the United States is not greatly different from 2.6. This figure is practically identical with that commonly assumed for the specific gravity of the earth's crust and corresponds to a weight of 165 pounds per cubic foot. Each 165 pounds of substance found in water, therefore, represents the erosion of approximately 1 cubic foot of the crust of the earth, and estimates of ultimate rock losses based upon these figures are probably not in error more than 8 or 10 per cent. Common earth or loam, however, contains a large amount of air space, or voids, and dry earth is estimated as weighing 80 to 110 pounds per cubic foot. If an estimate of erosion be made upon this basis the error for a large area will probably not be great, but may amount to 20 per cent or more when calculations are made for small areas. Finally a third factor for calculation is based upon an attempt to determine the volume of river sediment or mud banks that a given weight of suspended matter may form. Investigators working upon different streams in the United States have obtained results indicating that a cubic foot of sediment

may be produced by 50 to 125 pounds of dry material. The compactness of the mud is so variable that an estimate of this nature based upon an average of 90 pounds per cubic foot is likely to be in error by about 45 per cent. In view of the widely divergent values given for river sediment and for surface loam, the estimates for denudation expressed in millionths of an inch in depth from the entire drainage area and in years required for the erosion of 1 inch from the drainage area are based upon the assumption that 165 pounds of suspended or dissolved solids represent the removal of 1 cubic foot of the earth's crust. The factor 0.1917 has been computed on that basis. For the convenience of those who prefer a different basis of calculation, the following table of ratios is presented. The figures given in this report for denudation in inches can be recomputed by dividing them by the ratio corresponding to the weight given in column 1.

Ratios for recomputing denudation in inches.

Weight of material per cubic foot.	Corresponding specific gravity.	Ratio.
Pounds.		
165	2.64	1.00
150	2.40	.91
140	2.24	.85
130	2.08	.79
120	1.92	.73
110	1.76	.67
100	1.60	.61
90	1.44	.55
80	1.28	.49
70	1.12	.42
60	.96	.36
50	.80	.30

The estimates for the primary basins and for the whole United States are based upon the estimates for the secondary areas.

PROBABLE ACCURACY.

The majority of the figures for run-off per square mile per year are based upon discharge measurements extending over periods of seven years or more and are, with a few exceptions, within 10 per cent of the true average values. The drainage areas in square miles are so nearly correct that their errors are negligible in these calculations. The estimates of dissolved solids represent the average condition of the water for a period of one year or more. By comparison of annual averages for several streams in different years it has been estimated that the average for one year is generally not over 10 per cent from the correct average value, and it is undoubtedly true that the average total solids does not vary from year to year nearly so much as the

average run-off. On the other hand, suspended solids are subject to greater variation than run-off. Floods are always attended by extreme rises in suspended solids, and the amount of suspended matter is subject to enormous variation from place to place on account of changes in stream velocity, the character of the river bed, and other features. In consequence of these facts, it is possible that denudation estimates, based on average suspended matter for one year, may be in error as much as 50 per cent. When all these facts are considered in conjunction with the distance of the sampling stations from the mouths of the rivers, it may be estimated that the calculated figures for denudation are generally within 20 per cent of the true values. Only two significant figures, therefore, have been retained in the last five columns. In many streams of the arid and semiarid regions the yearly fluctuations in run-off are very great and the mineralization of the waters is very high, so that estimates of denudation in that part of the country are not so reliable as similar estimates for eastern rivers. As the analytical data for the northern Pacific, Hudson Bay, and western Gulf of Mexico basins are extremely meager, the estimated denudations for those areas may be more than 20 per cent in error, and further investigations in those regions must be made before reliable values can be calculated.

DISCUSSION OF SUMMARY.

The summary presents in tabular form denudation estimates for the primary drainage basins and for the whole United States. The figures for dissolved solids practically represent material carried into the ocean; the figures for suspended solids, on the other hand, represent more properly material carried to tide water, because the decrease in stream velocity at that point occasions a gradual deposition of the matter transported in solid form. The tons per square mile per year removed from different basins show interesting comparisons. In respect to dissolved matter, the southern Pacific basin heads the list with 177 tons, the northern Atlantic basin being next with 130 tons. The rate for Hudson Bay basin, 28 tons, is lowest; that for the Colorado and western Gulf of Mexico basins is somewhat higher. The denudation estimates for the southern Atlantic basin correspond very closely to those for the entire United States. The amounts are generally lowest for streams in the arid and semiarid regions, because large areas there contribute little or nothing to the run-off. The southern Pacific basin is an important exception to this general rule, presumably because of the extensive practice of irrigation in that area. The amounts are highest in regions of high rainfall, though usually the waters in those sections are not so highly mineralized as the waters of streams in arid regions.

Colorado River brings down the most suspended matter, delivering 387 tons per year for each square mile of its drainage basin. Though many small streams bring silt into the Great Lakes, sedimentation clears the water, and practically no suspended matter is transported by St. Lawrence River. In general much less suspended matter is carried by northern than by southern rivers, a phenomenon influenced probably more by the texture of the soil and the subsoil and the geologic character of the rocks than by stream velocity.

The detailed estimates throw considerable light upon the progress of erosion in different sections of the river valleys. The Mississippi, for instance, apparently discharges more material than is brought in by its tributaries, thus indicating that its lower valley is still being eroded. The lower Colorado, however, appears to be receiving deposits from both dissolved and suspended matter taken from its upland drainage area. The Rio Grande is similar to the Colorado in this respect.

The estimates reveal that the surface of the United States is being removed at the rate of thirteen ten-thousandths of an inch per year, or 1 inch in 760 years. Though this amount seems trivial when spread over the surface of the country, it becomes stupendous when considered as a total, for over 270,000,000 tons of dissolved matter and 513,000,000 tons of suspended matter are transported to tide water every year by the streams of the United States. This total of 783,000,000 tons represents more than 350,000,000 cubic yards of rock substance, or 610,000,000 cubic yards of surface soil. If this erosive action had been concentrated upon the Isthmus of Panama at the time of American occupation, it would have excavated the prism for an 85-foot level canal in about seventy-three days.

Summary.

Drainage basin.	Physical and chemical data.				Estimated denudation.								
	Area (square miles).	Solids (parts per million).		Run-off (second-feet per square mile).	Tons of solids per square mile per year.		Thousand tons of solids per year.		Millionths of an inch per year.		Years required for 1 inch.		
		Dissolved.	Suspended.		Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Total.
I. Northern Atlantic	159,400				130	39	20,800	6,100	680	200	1,500	5,000	1,100
II. Southern Atlantic	123,900				94	176	11,700	21,800	490	920	2,000	1,100	710
III. Eastern Gulf of Mexico	142,100				117	144	16,600	20,400	580	750	1,700	1,300	750
IV. Western Gulf of Mexico	315,700				36	72	11,400	22,700	190	380	5,300	2,700	1,800
V. Mississippi River	1,265,000				108	269	136,400	340,500	560	1,400	1,800	710	500
VI. Laurentian Basin	175,000				116	1	20,400	180	600	5	1,700	200,000	1,610
VII. Colorado River	230,000				51	387	11,700	89,000	270	2,000	3,800	500	440
VIII. Southern Pacific	72,700				177	75	12,800	5,500	920	390	1,100	2,600	760
IX. Northern Pacific	270,000				100	20	27,000	5,400	520	100	1,900	9,600	1,600
X. Great Basin	223,000				90	50	20,100	11,200	470	260	2,100	3,800	1,400
XI. Hudson Bay	62,000				28	21	1,700	1,300	150	110	6,800	9,100	3,900
Total	3,048,800						290,600	524,080					
The United States	3,088,500				94	170	290,600	524,080	490	890	2,040	1,130	730
The United States (Great Basin denudation being taken as zero)	3,088,500				87	166	270,500	512,880	460	870	2,190	1,150	760

Drainage basin.	Physical and chemical data.				Estimated denudation.								
	Area (square miles).	Solids (parts per million).		Run-off (second-feet per square mile).	Tons of solids per square mile per year.		Thousand tons of solids per year.		Millionths of an inch per year.		Years required for 1 inch.		
		Dissolved.	Suspended.		Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Total.
1. Northern Atlantic	159,400				130	39	20,795	6,147	680	200	1,500	5,000	1,100
1. St. Johns (in United States)	7,500			1.76	85	7	638	53	440	37	2,300	27,000	2,100
2. St. Croix (in United States)	1,100			2.61	100	8	110	9	520	42	1,900	24,000	1,800
3. Penobscot	8,500			1.96	90	8	765	68	470	42	2,100	24,000	2,000
4. Kennebec	5,970			1.84	85	7	508	42	440	37	2,300	27,000	2,100
Waterville, Me	4,270	48	4.0	1.76	83	7.3							
5. Androscoggin	3,500			2.14	100	8	350	28	520	42	1,900	24,000	1,800
Brunswick, Me	3,500	48		2.14	101								
6. Presumpscot	600			1.68	85	7	51	4	440	37	2,300	27,000	2,100
7. Saco	1,720			2.36	100	8	172	14	520	42	1,900	24,000	2,100
8. Merrimac	5,020			1.62	65	7	326	35	340	37	3,000	27,000	2,700
Lawrence, Mass	4,550	41		1.58	64								
9. Connecticut	11,100			1.99	90	8	999	89	470	42	2,100	24,000	2,000
Goodspeeds, Conn	10,900	45		1.99	88								
10. Blackstone	460				125	7	58	3	650	37	1,500	27,000	1,500
Valley Falls, R. I	440	74		1.71	125								
11. Thames	1,450				125	7	181	10	650	37	1,500	27,000	1,500
12. Housatonic	1,980			2.17	195	8	386	16	1,000	42	980	24,000	940
Gaylordsville, Conn	1,020		4.0	2.15		8.5							
Derby, Conn	1,920	92		2.15	195								
13. Hudson	13,400			1.90	190	30	2,544	402	990	160	1,000	6,400	870
Albany, N. Y	8,800	107	17.0	1.80	189	30							
Hudson, N. Y	9,530	108	16.0	1.82	193	29							
Mechanicsville, N. Y	4,500			1.81									
Dunsback Ferry (Mohawk River)	3,440			1.73									
14. Passaic	950			2.17	180	75	171	71	940	390	1,100	2,600	750
15. Raritan	1,110			2.15	180	75	200	83	940	390	1,100	2,600	750
Bound Brook, N. J	800	85	36.0	2.14	179	76							
16. Delaware	13,100			1.97	150	55	1,964	721	780	290	1,300	3,500	940
Lambertville, N. J	6,860	70	26.0	2.19	151	56							
17. Susquehanna	27,400			1.56	165	35	4,520	960	860	180	1,200	5,500	960
Danville, Pa	11,070	112	21.0	1.71	188	35							
Williamsport, Pa	5,640	74	18.0	1.68	123	30							
18. Potomac	14,300			1.21	125	95	1,787	1,358	650	500	1,500	2,000	870
Piedmont, W. Va	410			1.70									

Detailed estimates—Continued.

Drainage basin.	Physical and chemical data.				Estimated denudation.								
	Area (square miles).	Solids (parts per million).		Run-off (second-feet per square mile).	Tons of solids per square mile per year.		Thousand tons of solids per year.		Millionths of an inch per year.		Years required for 1 inch.		
		Dissolved.	Suspended.		Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Total.
I. Northern Atlantic—Continued.													
18. Potomac—Continued.													
Cumberland, Md.	620	130	29.0	1.70	217	49							
Millville, W. Va. (Shenandoah River)	3,000	140	39.0	1.07	147	41							
Point of Rocks, Md.	9,650			1.07									
Great Falls, Md.	11,400	115	85.0	1.12	127	94							
19. James.	10,400			1.35	115	95	1,195	988	600	500	1,700	2,000	900
Cartersville, Va.	6,230			1.33									
Richmond, Va.	6,820	89	71.0	1.33	117	93							
20. Minor Chesapeake Bay.	12,800			1.59	130	40	3,870	1,193	680	210	1,500	4,800	1,100
21. Minor North Atlantic.	17,000			2.18	94	176	11,688	21,775	490	920	2,000	1,100	710
II. Southern Atlantic.	123,900				85	80	425	400	440	420	2,300	2,400	1,200
1. Chowan.	5,000			1.40	101	256	984	2,490	530	1,300	1,900	750	540
2. Roanoke.	9,750			1.25									
South Boston, Va. (Dan River)	2,750	71	264.0	1.34	94	348							
Randolph, Va.	3,080	79	127.0	1.39	108	174							
3. Tar.	4,360			1.26	85	80	371	349	440	420	2,300	2,400	1,200
4. Neuse.	5,550			1.32	86	80	477	444	450	420	2,200	2,400	1,200
Raleigh, N. C.	1,000	73	68.0	1.19	86	80							
Selma, N. C.	1,170			1.19									
5. Cape Fear.	9,030			1.23	69	25	623	226	360	130	2,800	7,700	2,000
Wilmington, N. C.	9,030	57	21.0	1.23	69	25							
6. Pedee (Yadkin).	10,600			1.60	113	154	1,198	1,630	590	800	1,700	1,200	720
Salisbury, N. C.	3,400			1.69									
Pee Dee, N. C.	6,100	69	94.0	1.66	113	154							
7. Santee.	14,800			1.66	107	233	1,583	3,445	560	1,200	1,800	820	560
Camden, S. C. (Wateree River)	4,500	73	214.0	1.44	104	303							
Waterloo, S. C. (Saluda River)	1,060			1.85									
Columbia, S. C. (Saluda River)	2,350	62	54.0	1.85	113	98							
8. Savannah.	11,100			1.58	98	232	1,088	2,575	510	1,200	2,000	830	580
Augusta, Ga.	7,300	60	142.0	1.66	98	232							

9. Ogeechee	5,140			1.27	90	225	463	1,156	470	1,200	2,100	850	610
10. Altamaha	14,100			1.26	85	215	1,198	3,030	440	1,100	2,300	890	640
Macon, Ga. (Ocmulgee River)	2,420	69	174.0	1.31	86	224							
Dublin, Ga. (Oconee River)	4,180	68	171.0	1.24	83	209							
11. Minor South Atlantic	34,500				95	175	3,278	6,030	500	910	2,000	1,100	710
III. Eastern Gulf of Mexico	142,100				117	144	16,610	20,430	580	750	1,700	1,300	750
1. Suwanee	9,970			1.50	100	150	997	1,500	520	780	1,900	1,300	770
2. Apalachicola	18,800			1.61	103	159	1,936	2,988	540	830	1,900	1,200	730
Albany, Ga. (Flint River)	5,000	67	58.0	1.56	103	89							
West Point, Ga. (Chattahoochee River)	3,300	52	136.0	1.98	102	265							
3. Mobile	42,100			1.57	129	151	5,190	6,350	670	790	1,500	1,300	680
Selma, Ala. (Alabama River)	15,400	82	100.0	1.81	146	178							
Epes, Ala. (Tombigbee River)	8,830	94	100.0	1.06	98	104							
4. Pearl	8,650			1.42	75	58	649	502	390	300	2,600	3,300	1,400
Jackson, Miss	3,120	59	46.0	1.29	75	58							
5. Minor Eastern Gulf	62,700			1.50	125	145	7,838	9,090	650	760	1,500	1,300	710
IV. Western Gulf of Mexico	315,700				36	72	11,370	22,740	190	380	5,300	2,700	1,800
1. Brazos	48,800			.200									
Waco, Tex	32,300	1,136	1,188.0	.082	92	96	2,970	3,100					
2. Colorado (of Texas)	39,000			.097	24	26							
Austin, Tex	35,000	321	351.0	.075	24	26	878	952					
3. Rio Grande	248,000			.032									
United States area	130,000				25	78	3,250	10,140					
El Paso, Tex	38,600	700	14,140.0	.030	21	418							
Laredo, Tex. (United States area)	123,000	791	2,475.0	.032	25	78							
Pecos River	56,000				90	60							
Dayton, N. Mex	16,300	2,988	2,150.0	.032	94	68							
Carlsbad, N. Mex	19,800	2,680	331.0	.035	92	11							
V. Mississippi River:													
1. Main stream—													
Minneapolis, Minn	19,600	200	7.9	.810	159	6.3	3,120	124	830	33	1,200	30,000	1,200
Quincy, Ill	135,500	203	119.0	.538	108	63							
Jefferson Barracks, Mo	700,700	206	964.0	.263	53	250							
Menard, Ill	711,900	269	634.0	.263	70	164							
Memphis, Tenn	941,000	202	519.0	.546	109	279							
New Orleans, La	1,261,000	190	600.0										
At mouth	1,265,000			.560	105	331							
2. Minor lower eastern—													
Tributaries	29,000				80	60	2,320	1,740	420	310	2,400	3,200	1,400
3. Ohio River	214,000				190	200	40,600	42,750	990	1,000	1,000	960	490
Tennessee River	39,000				159	200							
Chattanooga, Tenn	21,400			1.71									
Gilbertsville, Ky	38,400	101	127.0	1.60	159	200							
Cumberland River	18,600				171	227							
Kuttawa, Ky	18,200	124	165.0	1.40	171	227							

Detailed estimates—Continued.

Drainage basin.	Physical and chemical data.				Estimated denudation.								
	Area (square miles).	Solids (parts per million).		Run-off (second-feet per square mile).	Tons of solids per square mile per year.		Thousand tons of solids per year.		Millionths of an inch per year.		Years required for 1 inch.		
		Dissolved.	Suspended.		Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Total.
V. Mississippi River—Continued.													
3. Ohio River—Continued.													
Green River	8,580				165	225							
Kentucky River	7,870				164	220							
Frankfort, Ky	5,140	104	142.0	1.60	164	223							
Licking River	3,300				160	220							
Big Sandy River	4,000				160	200							
Kanawha River	11,000				160	180							
Monongahela River	7,620				217	203							
Elizabeth, Pa	5,580	81	84.0	1.80	143	149							
McKeesport, Pa. (Youghiogheny River)	1,770	197	163.0	2.30	446	369							
Allegheny River	11,100				160	60							
Kittanning, Pa	8,690	87	30.0	1.62	139	48							
Brilliant, Pa	11,000	116	48.0		185	77							
Beaver River	3,100				180	65							
Muskingum River	7,740				232	67							
Zanesville, Ohio	5,830	244	70.0	.966	232	67							
Scioto River	6,400				220	68							
Great Miami River	5,400				210	68							
Dayton, Ohio	2,450	289	94.0	.737	210	68							
Wabash River	33,000				249	86							
Terre Haute, Ind	12,200			.737									
Vincennes, Ind	12,720	336	193.0		244	140							
White River	10,800				290	38							
Indianapolis, Ind. (West Fork)	1,520	450	38.0	.792	351	30							
Azalia, Ind. (East Fork)	2,100	279	48.0	.900	247	43							
Shoals, Ind. (East Fork)	4,900			.924									
Embarass River	2,450				212	49							
Lawrenceville, Ill	2,390	283	66.0	.76	212	49							
Little Wabash River	2,600				133	52							
Carmi, Ill	2,500	176	68.0	.77	133	52							
Minor tributaries	56,800												
Main stream:													
Wheeling, W. Va	23,800			1.72									

Cincinnati, Ohio	72,400	120	230.0	1.60	189	363							
Louisville Ky	85,000	150	350.0	1.50	221	517							
4. Big Muddy River	2,370				170	98	400	230	890	510	1,100	2,000	720
Murphysboro, Ill	2,250	225	129.0	.77	170	98							
5. Kaskaskia River	5,880				180	92	1,060	540	940	480	1,100	2,100	700
Carlyle, Ill	2,720	248	126.0	.74	180	92							
6. Illinois River	27,900				218	118	6,080	3,290	1,100	620	880	1,600	570
Kampsville, Ill	26,730	267	145.0	.83	218	118							
7. Rock River	10,970				200	180	2,190	1,970	1,000	940	960	1,100	500
Rockton, Ill	6,150			.773									
Rock Falls, Ill	8,640	267	236.0		203	179							
8. Wisconsin River	12,280				140	7	1,720	86	730	37	1,400	27,000	1,300
Necedah, Wis	5,800			1.45									
Portage, Wis	8,600	98	4.6		140	6.6							
9. Chippewa River	9,570				116	5	1,110	48	600	26	1,700	38,000	1,600
Eau Claire, Wis	6,740	90	3.7	1.31	116	4.7							
10. St. Croix River	7,660				120	5	920	38	630	26	1,600	38,000	1,500
11. Minor upper:													
Eastern tributaries	10,000				180	90	1,800	900	940	470	1,100	2,100	710
12. Minnesota River	16,100				89	26	1,420	418	460	140	2,200	7,400	1,700
Mankato, Minn	13,400			0.186									
Shakopee, Minn	15,100	480	142.0		88	26							
13. Wapsipinicon River	2,570				145	50	370	128	760	260	1,300	3,800	980
14. Iowa River	12,400				145	50	1,800	620	760	260	1,300	3,800	980
Iowa City, Iowa	3,320	247	120.0	.573	139	68							
Cedar Rapids, Iowa (Cedar River)	6,320	228	61.0	.656	147	39							
15. Des Moines River	14,700				169	349	2,480	5,130	880	1,800	1,100	550	370
Keosauqua, Iowa	14,300	312	642.0	.551	169	349							
16. Missouri River	528,000				50	290	26,400	153,100	260	1,500	3,800	660	560
Florence, Nebr	323,000	454	2,059.0	.154	69	312							
Omaha, Nebr	323,000			.154									
Kansas City, Mo	430,000	426	2,032.0	.143	60	286							
Ruegg, Mo	528,000	346	1,890.0	.157	53	292							
West Alton, Mo	528,000	294	1,138.0	.157	45	176							
Milk River	26,700												
Havre, Mont	7,300	712	1,331.0	.035	25	46							
Yellowstone River	69,700												
Glendive, Mont	66,090	375	853.0	.188	70	158							
Platte River	83,800												
Fremont, Nebr	71,400	302	392.0		39	51							
Columbus, Nebr	70,400			.132									
Kansas River	61,400												
Lecompton, Kans	58,600			.191									
Holliday, Kans	61,100	383	612.0		72	115							
17. Arkansas River	189,000				120	140	22,700	26,450	630	730	1,600	1,400	740
Arkansas City, Kans	44,500	1,284	1,736.0	.045	57	77							
Little Rock, Ark	158,000	630	748.0	.197	122	145							
18. Red River	90,000				160	240	14,400	21,600	840	1,300	1,200	800	480
Shreveport, La	56,900	561	870.0	.285	157	244							
19. Minor western tributaries	63,000				145	50	9,140	3,150	760	260	1,300	3,800	980

Detailed estimates—Continued.

Drainage basin.	Physical and chemical data.				Estimated denudation.								
	Area (square miles).	Solids (parts per million).		Run-off (second-feet per square mile).	Tons of solids per square mile per year.		Thousand tons of solids per year.		Millionths of an inch per year.		Years required for 1 inch.		
		Dissolved.	Suspended.		Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Total.
V. Mississippi River—Continued.													
Cumulative summary:													
1. Above Quincy, Ill.:													
Mississippi at Minneapolis, Minn	19,600				159	6.3	3,120	124	830	33	1,200	30,000	1,200
Minnesota River	16,100				88	26	1,420	418	460	140	2,200	7,400	1,700
Wapsipinicon River	2,570				145	50	370	128	760	260	1,300	3,800	980
Iowa River	12,400				145	50	1,800	620	760	260	1,300	3,800	980
Des Moines River	14,700				169	349	2,480	5,130	880	1,800	1,100	550	370
St. Croix River	7,660				120	5	920	38	630	26	1,600	38,000	1,500
Chippewa River	9,570				116	5	1,110	48	600	26	1,700	38,000	1,600
Wisconsin River	12,280				140	7	1,720	86	730	37	1,400	27,000	1,300
Rock River	10,970				200	180	2,190	1,970	1,000	940	960	1,100	500
Minor streams	29,650				157	63	4,660	1,880	820	330	1,200	3,000	870
Mississippi at Quincy, Ill.	135,500												
Estimated from tributaries					146	77	19,790	10,442	760	400	1,300	2,500	860
Actually determined					108	63	14,640	8,540	560	330	1,800	3,000	1,100
Average					127	65	12,215	9,491	660	340	1,500	3,000	1,000
2. Above Menard, Ill.:													
Mississippi at Quincy, Ill	135,500				146	77	19,790	10,442	760	400	1,300	2,500	860
Illinois River	27,900				218	118	6,080	3,290	1,100	620	880	1,600	570
Missouri River	528,000				50	290	26,400	153,100	260	1,500	3,800	660	560
Kaskaskia River	5,880				180	92	1,060	540	940	480	1,100	2,100	700
Minor streams	14,620				145	50	2,120	731	760	260	1,300	3,800	980
Mississippi at Menard, Ill.	711,900												
Estimated from tributaries					78	236	55,450	168,103	410	1,200	2,500	810	610
Actually determined					70	164	49,850	116,700	360	860	2,700	1,200	820
Average					74	200	52,650	142,402	390	1,000	2,600	960	700

3. Above Memphis, Tenn.:													
Mississippi at Menard, Ill.	711,900				78	236	55,450	168,103	410	1,200	2,500	810	610
Big Muddy River	2,370				170	98	400	230	890	510	1,100	2,000	720
Ohio River	214,000				190	200	40,600	42,750	990	1,000	1,000	960	490
Minor streams	12,730				145	50	1,840	636	760	260	1,300	3,800	980
Mississippi at Memphis, Tenn	941,030												
Estimated from tributaries					104	225	98,290	211,719	540	1,200	1,800	850	580
Actually determined					109	279	102,500	262,400	570	1,500	1,800	690	490
Average					106	252	100,395	237,060	550	1,300	1,800	760	540
4. Mouth of river:													
Mississippi at Memphis, Tenn	941,000				104	225	98,290	211,719	540	1,200	1,800	850	580
Arkansas River	189,000				120	140	22,700	26,450	630	730	1,600	1,400	740
Red River	90,000				160	240	14,400	21,600	840	1,300	1,200	800	480
Minor streams	45,000				103	56	4,640	2,540	540	290	1,900	3,400	1,200
At mouth	1,265,000												
Estimated from tributaries					111	208	140,030	262,309	580	1,100	1,700	920	600
Determined from analyses at New Orleans					105	331	132,820	418,720	550	1,700	1,800	580	440
Average					108	269	136,425	340,514	560	1,400	1,800	710	510
VI. Laurentian Basin: [a]													
United States area	175,000				116	1	20,360	181	600	5	1,700	200,000	1,600
1. Lake Superior	76,100			1.02	60	1							
United States area	48,600				60	1	2,920	49	310	5	3,200	200,000	3,100
Saulte Ste. Marie, Mich.	76,100	60	Trace.										
2. Lakes Michigan-Huron	137,800			.874									
United States area	71,300				126	.8	8,950	59	660	4	1,500	250,000	1,500
3. Lakes Superior-Michigan-Huron	213,900			.924	99	.9							
United States area	119,900				99	.9	11,870	108	520	5	1,900	200,000	1,900
Chicago, Ill. (drainage canal)	213,900	130	Trace.	.022	3	.0							
Port Huron, Mich. (St. Clair River)	213,900	108	Trace.	.902	96	.9							
4. Lake Erie	80,800			.539									
United States area	23,400				184	.5	4,310	11	960	3	1,000	330,000	1,000
5. Lakes Superior-Michigan-Huron-Erie	254,700			.863	113	.8							
United States area	143,300				113	.8	16,180	119	590	4	1,700	250,000	1,700
Chicago, Ill. (drainage canal)	254,700	130	Trace.	.018	2.3	.0							
Buffalo, N. Y. (Niagara River and New York canals)	254,700	133	Trace.	.845	111	.8							

[a] Figures are based upon assumption that unit denudation above Ogdensburg is the same for the United States and Canada.

Detailed estimates—Continued.

Drainage basin.	Physical and chemical data.				Estimated denudation.								
	Area (square miles).	Solids (parts per million).		Run-off (second-feet per square mile).	Tons of solids per square mile per year.		Thousand tons of solids per year.		Millionths of an inch per year.		Years required for 1 inch.		
		Dissolved.	Suspended.		Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Total.
VI. Laurentian Basin—Continued.													
6. Lake Ontario	33,000			1.04									
United States area	18,000				144	1	2,600	18	750	5	1,300	200,000	1,300
7. Lakes Superior–Michigan–Huron–Erie–Ontario	287,700			.884	116	.9							
United States area	161,300				116	.9	18,780	137	600	5	1,700	200,000	1,600
Chicago, Ill. (drainage canal)	287,700	130	Trace.	.016	2.1	.0							
Buffalo, N. Y. (New York canals)	287,700	133	Trace.	.008	1.1	.0							
Ogdensburg, N. Y. (St. Lawrence River)	287,700	134	Trace.	.859	113	.9							
8. St. Lawrence River (below Ogdensburg, N. Y.)—													
United States area	13,660				116	3.2	1,580	44	600	17	1,700	59,000	1,600
Oswegatchie River—													
Ogdensburg, N. Y.	1,580	77	10.0	1.72	130	17							
Lake Champlain	7,900	66	Trace.		113	1.7							
Rouses Point, N. Y.	7,750			1.74									
VII. Colorado River:													
United States area	230,000				51	387	11,730	89,010	270	2,000	3,800	500	440
Yuma, Ariz	225,000	710	5,354.0	.0733	51	387							
1. Gila	71,100				80	[a] 225	5,690	16,000	420	1,200	2,400	860	630
Salt River	13,000				150	235							
Roosevelt, Ariz.	5,760	646	1,300.0	.238	151	304							
McDowell, Ariz. (Verde River)	6,000	363	1,137.0	.141	50	158							
Mesa, Ariz.	12,260	1,090	1,274.0	.189	203	237							
Gila River					13	210							
San Carlos, Ariz.	13,500	811	4,682.0	.015	12	69							
Florence, Ariz.	17,850	944	14,130.0	.015	14	209							
2. Little Colorado	31,000				11	134	340	4,150	57	700	18,000	1,400	1,300
Woodruff, Ariz.	6,000	602	7,149.0	.019	11	134							
3. Grand	26,200				198	470	5,190	12,310	1,000	2,400	970	410	[a] 290
Palisades, Colo	8,550	[a] 429	[b] 1,358.0	.546	230	730							
Whitewater, Colo. (Gunnison River)	7,870	484	553.0	.350	167	190							

4. Green	41,000				90	165	3,690	6,760	470	860	2,100	1,200	750
Jensen, Utah	26,600	369	679.0	.247	90	165							
VIII. Southern Pacific	72,700				177	75	12,850	5,460	920	390	1,100	2,600	760
1. Minor Southern Pacific	22,800			.325	196	71	4,470	1,620	1,000	370	980	2,700	720
Soledad, Cal. (Arroyo Seco)	215	284	33.0	.793	222	26							
Santa Maria, Cal. (Santa Maria River)	1,000	2,412	1,302.0		204	110							
Santa Barbara, Cal. (Santa Ynez River)	207	714	64.0	.495	348	31							
Calabasas, Cal. (Malibu Creek)	97	717	61.0	.375	265	23							
Mentone, Cal. (Santa Ana River)	182	139	53.0	.409	56	21							
Pala, Cal. (San Luis Rey)	318	321	142.0	.352	111	49							
2. San Francisco Bay	49,900				168	77	8,380	3,840	880	400	1,100	2,500	780
Sacramento River	31,400			1.45	172	86							
Sacramento, Cal	29,500	121	60.0	1.45	172	86							
San Joaquin River [c]	16,500			1.02	162	60							
Lathrop, Cal	12,500	161	60.0	1.02	162	60							
IX. Northern Pacific	[d] 270,000				100	20	27,000	5,400	520	100	1,900	9,600	1,600
X. Great Basin	[d] 223,000				90	50	20,070	11,150	470	260	2,100	3,800	1,400
XI. Hudson Bay (in United States)	62,000				28	21	1,740	1,300	150	110	6,800	9,100	3,900
Red River of the North–													
Total area in United States	50,000				28	21	1,400	1,050	150	110	6,800	9,100	3,900
Grand Forks, N. Dak	25,000	[e] 200	[e] 150.0	.141	28	21							

[a] Suspended matter probably far too low.
[b] Analyses cover only portion of year. Results appear too high for an average.
[c] Excluding Tulare Lake.
[d] Analytical data extremely meager.
[e] Estimated from four analyses.

CONTROL OF CATCHMENT AREAS.

By Horatio N. Parker.

Catchment areas, annual consumption, and total money investment of the water works of 42 cities which derive their water supplies from impounded surface waters and which have populations of over 30,000.

City.	Catchment area.	Reservoir capacity.	Annual consumption.	Total investment.		
				Cost of construction.	Bonded indebtedness.	Maintenance.
	Sq. miles.	*Gallons.*	*Gallons.*			
Altoona, Pa.	9.00	[a] 425,000,000	547,500,000	$910,148	$479,000	$45 090
Baltimore, Md.	347.00	2,310,000,000	22,995,000,000	12,000,000	850,000	400,000
Boston, Mass.	[b] 212.38	82,966,530,000	40,250,000,000	40,459,778	40,500,000	318,052
Bridgeport, Conn.	40.80	10,000,000	7,300,000,000	.....	.....	.....
Brockton, Mass.	7.70	5,700,000,000	714,340,000	1,713,300	1,485,000	38,000
Butte, Mont.	.....	290,000,000	2,190,000,000	.....	.....	.....
Cambridge, Mass.	6.80	2,270,000,000	3,386,180,000	6,467,153	3,787,600	75,702
Charleston, S. C.	49.00	3,127,820,000	1,204,500,000	2,456,682	1,250,000	52,245
Denver, Colo.	3,910.00	110,000,000,000	15,881,000,000	.....	.....	.....
Elmira, N. Y.	.....	117,500,000	1,546,900,000	895,000	.....	115,000
Fall River, Mass.	27.54	.....	1,640,000,000	2,076,450	1,550,000	124,972
Fitchburg, Mass.	7.40	2,000,000	1,095,000,000	1,400,000	446,000	37,300
Hartford, Conn.	13.00	2,035,000,000	2,190,000,000	3,567,191	675,000	150,000
Haverhill, Mass.	20.10	128,000,000	1,839,000,000	1,463,047	610,833	25,137
Holyoke, Mass.	18.05	1,600,000,000	2,127,840,000	1,295,308	350,000	61,712
Jersey City, N. J.	.....	129,200,000	12,045,000,000	5,200,000	600,000	445,060
Johnstown, Pa.	5.50	283,000,000	.....	1,500,000	.....	.....
Los Angeles, Cal.	502.50	898,000,000	11,680,000,000	[c] 3,983,693	[d] 3,480,250	201,107
Lynn, Mass.	.....	.....	1,873,450,000	2,900,891	1,778,500	117,389
Newark, N. J.	.....	9,000,000,000	93,482,500,000	8,959,790	7,993,500	250,000
New Bedford, Mass.	[e] 12.80	[f] 5,550,000,000	2,524,661,000	3,332,800	1,638,000	109,443
New Haven, Conn.	56.40	2,837,000,000	8,395,000,000	.....	.....	.....
New York, N. Y. (boroughs of Manhattan and Bronx)	[g] 382.00	[h] 108,638,000,000	[h] 119,720,000,000	[i] 86,359,562	.....	1,000,000
Norfolk, Va.	.....	.....	2,482,000,000	1,250,000	.....	.....
Oakland, Cal.	.....	6,300,000,000	.....	4,520,000	.....	100,000
Pawtucket, R. I.	27.80	1,475,600,000	2,633,000,000	1,946,848	1,285,000	53,153
Portland, Me.	.....	30,000,000	2,190,000,000	2,677,970	.....	.....
Portland, Oreg.	.....	6,000,000	6,935,000,000	5,204,650	2,900,000	78,516
Reading, Pa.	218.60	186,022,000	3,768,260,000	33,213,725	400,000	50,316
Rochester, N. Y.	[j] 66.20	229,500,000	5,621,000,000	9,028,000	5,610,000	115,000
St. Paul, Minn.	.....	18,000,000	3,732,000,000	4,517,329	2,367,000	60,337
Salem, Mass.	.....	20,000,000	1,090,426,000	1,947,200	143,000	31,306
Salt Lake City, Utah.	.....	9,012,000	5,110,000,000	4,810,000	1,575,000	55,000
San Francisco, Cal. (prior to fire)	.....	29,000,000,000	12,344,665,000	.....	.....	554,000
Scranton, Pa.	.....	2,000,000,000	9,125,000,000	.....	.....	.....
Springfield, Mass.	[k] 18.00	1,500,000,000	4,000,000,000	2,509,525	555,000	54,700
Syracuse, N. Y.	70.25	121,000,000	4,380,000,000	5,000,000	4,075,000	100,000
Taunton, Mass.	52.00	10,300,000,000	818,774,000	1,367,801	853,500	33,988
Waterbury, Conn.	19.50	920,000,000	2,728,831,000	1,819,640	865,000	24,000
Wilkesbarre, Pa.	.....	4,000,000	.....	.....	.....	.....
Worcester, Mass.	.....	2,550,000,000	2,954,617,000	4,406,202	3,830,000	60,000

[a] Exclusive of a reservoir of 300,000,000 gallons capacity.
[b] Metropolitan Water Works.
[c] Amount spent since the works were taken over by the city in February, 1902.
[d] Original, 4,017,500.
[e] Exclusive of a storage reservoir in Acushnet, which has a catchment area of 5.25 square miles.
[f] An additional storage reservoir of 1,600,000,000 gallons capacity is under construction.
[g] On Croton, Bronx, and Byram rivers.
[h] On Croton River, including the new Croton reservoir to be finished in 1911, and on Bronx and Byram rivers.
[i] 1832 to 1898, inclusive.
[j] Exclusive of Hemlock Lake.
[k] Little River supply, now 40 per cent completed, is to replace present supply; will have a catchment area of 48 square miles and storage capacity of 2,600,000,000 gallons.

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